XYZ Test Report

DOCSIS 3.1 Validation

Software x.y.z
Customer
Date

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Executive Summary

Previously Customer has deployed DOCSIS 3.1 equipment (both CCAP and CM) to upgrade its network. Both OFDM and OFDMA are now being deployed and both the CCAP platform and DOCSIS 3.1 cable modem have a software upgrade available with a lot of bug fixes and performance upgrades.

To validate the correct behavior of the equipment in the current and future field configuration, these new software versions need to be tested, and the hardware needs to be validated for these configurations. Excentis has created a set of test plans to validate Customer's DOCSIS 3.1 equipment in different stages of the deployment cycle and these are used for this test campaign.

This report focusses on the cable modem functionality, where also some new topics are under test (multicast, SIP, Wi-Fi band steering) based on new services or issues from Customer's field experience.

The test campaign has uncovered **many issues** of which some **can have large customer impact**.

The most important issues are:

OFDM Power Reporting: Of the ten tested modems, one does not accurately report the downstream receive power, which could lead to incorrect HFC condition conclusions in monitoring software tools.

Long Term Loading: The modem cannot operate with high load at maximum temperature for twelve hours. After seven hours at 40°C the modem starts rebooting.

OFDM Profile Management: With narrowband noise interfering the PLC of an OFDM downstream channel, the modem does not report the channel as lost. Because of this the CMTS continues using the channel for data to the modem, and every packet sent on that channel is lost. Additionally, the modem sends unexpected NCP and profile 0 recovery CM-STATUS messages in an interfered environment, which also lead to unwanted profile recoveries and downstream packet loss.

OFDMA Profile Management: When a modem is booted in an interfered environment, it cannot successfully recover a higher OFDMA profile after the interference is removed. When the noise is gone, the CM rejects the CMTS profile assignment, and is forced to reboot.

Wi-Fi Test Results: The Access Point (AP) does not assign the downlink airtime equally over the connected clients in the 5 GHz band, with some clients getting almost no airtime. The results are however not that uncommon when compared to other APs on the market. The same remark applies to the testcase with an interfering AP. The newly added Wi-Fi band steering test fails as well, because the AP does not direct the modem to go from 2.4 GHz to 5 GHz.

L2VPN Test Results: In an L2VPN configuration the modem does not forward broadcast downstream packets. This can have a large negative impact, specifically, but not limited to, the ARP packets in the L2VPN network. The modem also incorrectly interprets the Downstream Unencrypted Traffic (DUT) filtering parameter and enables this feature when disabled in the modem configuration file, and vice-versa.

1 Test Result Overview

The tests were executed according to the following test plans:

- Customer DOCSIS3.1 CPE Acceptance Test Plan - Batch Testing- V03.pdf
- Customer DOCSIS3.1 CPE Acceptance Test Plan – Product Selection - V04.pdf
- Customer DOCSIS3.1 CPE Acceptance Test Plan - SW readiness- V04.pdf

The CMTS VENDOR CMTS configuration was discussed and aligned with Customer's configuration. The stability test on the modem was run simultaneously with the CMTS VENDOR CMTS stability test.

Hardware validation and batch testing

Test	Result
SC-QAM Upstream Power Calibration and Range Verification	PASS
SC-QAM Downstream Power Calibration and Range Verification	PASS with remark
Return Loss	PASS
OFDM Downstream Power Calibration and Range Verification	FAIL
OFDMA Upstream Power Calibration and Range Verification	PASS
OFDMA Noise and Spurs	PASS
Downstream Tilt Validation	Delayed
EuroDOCSIS 3.0 & DOCSIS 3.1 Basic Operation and Traffic Forwarding	PASS with remark
Throughput and Latency Determination	PASS with remark
Power Consumption	FAIL
Long Term Loading	FAIL
Wi-Fi Maximum Throughput	N/A

Software validation

Test	Result
Stability Test	PASS with remark
Monitoring	PASS
TCP Subscription Speeds ED3.0 & D3.1	PASS
Partial Service ED3.0 & D3.1	PASS with remark
OFDM Profile Management	FAIL
OFDM/OFDMA Mixed Modulations and Exclusions	PASS
OFDMA Profile Management	FAIL
Airtime Fairness (Point-to-multipoint throughput)	FAIL
Neighboring APs - Congestion testing (co-channel)	FAIL
Wi-Fi Band Steering	FAIL
L2VPN forwarding	FAIL
TOS Classification	PASS
DUT filtering	FAIL

2 DUT Details

2.1 Modem under test

The DOCSIS 3.1 modem under test was the [redacted] with software [redacted], and the Customer samples have two different BOOTR versions reflected in the system descriptor.

System descriptor:

- [redacted]
- [redacted]

All relevant tests were executed with the CM configuration files provided by Customer.

2.2 CMTS used for testing

For this test run the XXX CMTS with general available software version a.b was used:

[redacted]

All tests were executed with the CMTS config aligned with Customer. The CMTS config was a mix of EuroDOCSIS 3.0 (SC-QAM and ATDMA) & DOCSIS 3.1 (OFDM and OFDMA). Details on that config are added in Appendix A.

3 Hardware Validation and Batch Testing

3.1 SC-QAM Upstream Power Calibration and Range Verification

This test verifies the capability of the CM to accurately report its transmission power in the docsIf3CmStatusUsTxPower MIB, the docsIf31CmUsScQamChanTxPsd MIB, and the RNG-REQ, as required by the DOCSIS 3.0 and 3.1 specifications. This is verified over the whole power range in approximately 10 steps of approximately 3 dB.

Result: PASS

The CM reports the upstream power always within the allowed 2 dB offset.

Observations

The CM reported on average 0.75 dB below the measured power value. This was within the allowed 2 dB deviation window. The deviation was very similar over the channels and the power range, with a worst case of 1.1 dB.

3.2 SC-QAM Downstream Power Calibration and Range Verification

This test verifies the capability of the modem to accurately report the SC-QAM downstream channel power in the docsIfDownChannelPower MIB as required by the DOCSIS 3.0 PHY specification. This is verified over the whole power range in steps of 1 dB. Both the absolute accuracy (power reporting 3 dB accurate) and the relative accuracy (reported accuracy of 1 dB power change) are verified. This is verified on ten Vendor A samples.

Result: PASS with remark

All ten modems reported the SC-QAM downstream power always within the allowed 3 dB offset. The **relative accuracy** however was, while on average 0.1 dB, in the **worst cases relatively high**, up to 1.7 dB for one modem.

Observations

The CMs reported on average with a 0.6 dB accuracy, both above and below the actual received downstream power. The maximum power difference was 1.9 dB. The relative accuracy in reporting a power difference of approximately 1 dB was on average 0.1 dB. While this average was acceptably low, two modems reported with a worst-case accuracy of significantly more (0.9 and 1.7 dB). Also for these modems, the *average* relative power reporting accuracy over all channels and power jumps was as low as 0.1 dB.

One sample [redacted]) went offline during this test. Such high downstream power variations as experienced in this test covering the full downstream power range, are however not expected in the field.

The table below gives the raw values for all ten samples.

CM MAC	Average absolute accuracy [dB]	Worst case absolute accuracy [dB]	Average relative accuracy [dB]	Worst case relative accuracy [dB]
[redacted]	0.3	1.0	0.1	0.4
[redacted]	0.8	1.7	0.1	**0.9**
[redacted]	0.5	1.1	0.1	0.4
[redacted]	0.8	1.7	0.1	0.6
[redacted]	0.5	1.4	0.1	**1.7**
[redacted]	0.6	1.4	0.1	0.6
[redacted]	0.2	0.8	0.1	0.5
[redacted]	0.3	1.1	0.1	0.4
[redacted]	1.2	1.9	0.1	0.5
[redacted]	1.0	1.6	0.1	0.5
[1] This sample went offline during the test.				

Table 1: Modem SC-QAM downstream power reporting accuracy values

3.3 Return Loss

This test measures the return loss on a CM across its operating frequency range in both upstream and downstream up to the frequencies supported by the modem.

Result: PASS

The modem return loss is within specifications (> 6 dB).

Observations

The worst return loss, 8.7 dB, was measured at 910 MHz for the 85 MHz diplexer. The worst return loss for the 204 MHz diplexer, 7.0 dB, was measured at 1023 MHz. Both values were well above the required 6 dB.

3.4 OFDM Downstream Power Calibration and Range Verification

This test verifies the capability of the modem to accurately report the OFDM channel power in the docsIf31CmDsOfdmChannelPowerRxPower MIB as required by the DOCSIS 3.1 PHY specification. This is verified over the whole power range in steps of 1 dB. Both the absolute accuracy (power reporting 3 or 5 dB accurate, depending on the power value) and the relative accuracy (no specification requirement) are verified. This is verified on ten Vendor A samples.

Result: FAIL

One of the ten tested samples had a downstream power reporting **accuracy of more than 3 dB** for several power settings in eight 6 MHz blocks. With a maximum deviation of 3.11 dB, this is still very close to the limit. The relative accuracy was, on average 0.1 dB, and in the worst cases relatively high, up to 0.8 dB. Additionally, **three modems** sometimes **reported bogus power values** in the middle of the test. In reruns of the same test, this did not consistently occur.

Observations

The CMs reported on average with a 1 dB accuracy, both above and below the actual received downstream power. Most often for the higher frequencies the modems reported relatively slightly lower powers than for the lower frequencies of the OFDM downstream channel. The maximum power deviation was 3.11 dB, which is slightly higher than the allowed limit of 3 dB for that specific power setting. This was the case for only one of the ten tested modems. The other nine samples had a maximum deviation varying between 1.2 dB and 2.9 dB. The relative accuracy in reporting a power difference of approximately 1 dB was on average 0.1 dB, with a worst-case accuracy of 0.8 dB.

Six samples went offline during this test. Such high downstream power variations as experienced in this test covering the full downstream power range, are however not expected in the field.

One additional remark regarding strange behavior is that three modems in the middle of the test started reporting bogus power values for the OFDM downstream channel. The modem was still successfully online, it reported good SNR for the channel and the codeword counters on the OFDM channel increased, but in the docsIf31CmDsOfdmChannelPowerTable all power values for all frequency bands were set to one fixed value. Only after a reboot of the modem, it reported the downstream properly again. This fixed value was not always the same (values seen: -6.7, 3.8, 14.0, 14.7, 15.1, and 25.2 dBmV), and did not occur in every rerun of the test. This occurred only after the downstream receive power was at least 11 dB increased.

The table below gives the raw values for all ten samples.

CM MAC	Average absolute accuracy [dB]	Worst case absolute accuracy [dB]	Average relative accuracy [dB]	Worst case relative accuracy [dB]
[redacted]	1.1	2.5	0.1	**0.8**
[redacted]	1.8	2.9	0.1	0.6
[redacted]	0.5	1.5	0.1	0.4
[redacted]	0.6	1.5	0.1	0.6
[redacted]	0.6	1.4	0.1	0.4
[redacted]	0.6	1.2	0.1	0.5

[redacted]	0.8	1.8	0.1	0.4
[redacted]	1.5	2.6	0.1	0.4
[redacted]	2.2	**3.1**	0.1	0.6
[redacted]	0.5	1.3	0.1	0.7

[1] These samples went offline during the test.

[2] These samples reported bogus power values in the middle of testing.

Table 2: Modem OFDM downstream power reporting accuracy values

3.5 OFDMA Upstream Power Calibration and Range Verification

This test verifies the capability of the CM to accurately report its OFDMA transmission power in the docsIf31CmUsOfdmaChanTxPower MIB and the RNG-REQ, as required by the DOCSIS 3.1 specification. This is verified over the whole power range in approximately 10 steps of approximately 3 dB.

Result: PASS

The CM reports the OFDMA transmission powers correctly and supports the whole power range.

Observations

The CM correctly reported its transmission power both in the MIB and in the RNG-REQ. The maximum observed difference was 0.2 dB, with an average accuracy of 0.1 dB. There was no significant difference between the accuracy in the lower or higher power range.

3.6 OFDMA Noise and Spurs

This test verifies if the DUT behaves as per noise and spurs requirements of the DOCSIS 3.1 PHY specification.

Result: PASS

The CM complies to the noise and spurs requirement, both on-burst as off-burst.

3.7 Downstream tilt validation

This test has been delayed due to Customer setup constraints and will be reprised at a later time.

3.8 EuroDOCSIS 3.0 & DOCSIS 3.1 Basic Operation and Traffic Forwarding

This test verifies the registration, bonding and traffic forwarding of legacy EuroDOCSIS 3.0 SC-QAM channels together with DOCSIS 3.1 OFDM(A) channels.

The CMTS is for this test configured as in the throughput and latency determination test:

32 SC-QAM + 2 OFDM downstream channels and 6 ATDMA + 1 OFDMA upstream channel

Result: PASS with remark

The CM was operational as expected and forwarded traffic without loss in the configuration above.

During **another test** however on a different CMTS configuration, the modem did **not successfully forward** data at maximum rate for fifteen minutes.

Observations

The CM was online on 30 SC-QAM + 2 OFDM downstream channels and 6 ATDMA + 1 OFDMA upstream channels. The upstream receive powers on the different channels were set slightly different on the CMTS to mimic the monitoring tool behavior. At 90% of the maximum throughput, as defined in the throughput and latency determination test, the CM was able to send 15 minutes of data (500 byte UDP packets) without loss. Configured traffic speeds were 3.4 Gbps downstream and 760 Mbps upstream.

However, in a different test similar traffic was sent on the original Customer configuration with one OFDM channel, and in this scenario the traffic was always not stable for fifteen minutes. With bidirectional traffic at maximum rate, the downstream throughput dropped with almost 50% after five to ten minutes. No CM-STATUS messages were sent by the modem. After restarting the traffic, the full rate was achieved once again. This behavior was observed during the partial service test, and while not part of that specific test, this does mimic the scenario for this traffic forwarding test. This specific behavior on that exact RF configuration was not further investigated and could have been both modem and CMTS related.

3.9 Throughput and Latency Determination

This test determines the maximum UDP and TCP forwarding throughput of the DUT between the RF and LAN interface. Once the value for UDP is determined, the latency with approximately 80% of this UDP throughput value is measured as well. The maximum throughput using all Ethernet ports is verified with smallest and biggest packet size. Both upstream and downstream are verified simultaneously, with IPv4 and IPv6 traffic. For this test, the CMTS was configured with 32 SC-QAM + 2 OFDM downstream channels and 6 ATDMA + 1 OFDMA upstream channel.

Result: PASS with remark

The CM throughput values are within the expected boundaries. The **downstream latency and jitter** are however **slightly larger** than what is considered good. It must be noted that the CMTS can have a huge impact on this as well.

Observations

- The test could not be executed with 2000 byte packets due to CMTS limitations. To overcome this, the throughput is measured with 1514 byte packets. It was verified using another CMTS that the modem is able to forward 2000 byte packets. The measurements with 1514 byte packets were close to the expected maximum.
- In both upstream and downstream, throughput was significantly lower for small packet sizes, compared to larger packet sizes. For upstream traffic with small packet sizes, a ramp up of the speed was observed at the beginning of the flow. Only after 20 seconds the maximum throughput was reached. For large packets, this was not observed.

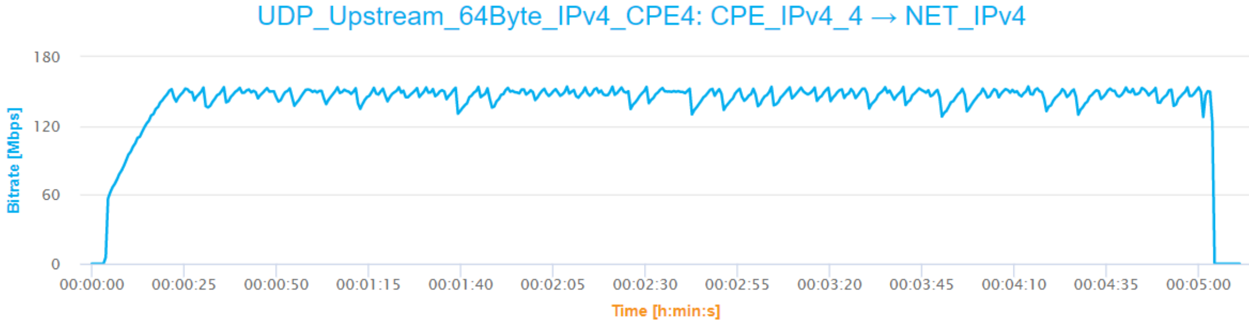


Figure 1: ramp up of upstream speed for small packets

- The average latency was below 6.8 ms for upstream (considered good when below 8 ms) and below 5 ms for downstream (considered good when below 2 msec) UDP traffic. The jitter downstream was below 1.5 ms (considered good when below 1 ms) and for upstream below 1.2 ms (considered good when below 5 msec). Because of the aforementioned upstream throughput ramp-up with small packets, each such high-rate upstream traffic flow started with packet loss, and high latency values. So for the upstream jitter, the traffic scenarios with small packets were not taken into account. Both downstream latency and jitter were higher than expected and higher compared to previous test runs, but this was the first throughput test run executed on the CMTS VENDOR CMTS, which may have impacted this as well. It was also noted the minimum latency was lower when only one Ethernet port was used. Spreading the traffic over all Ethernet ports resulted in slightly higher (0.5 ms) latency values.
- It was verified whether the total throughput was not limited to the four one-Gbps Ethernet ports by adding Wi-Fi traffic. The total throughput could be increased compared to the situation with only traffic through the Ethernet ports, however, there was a total upper limit of 4 Gbps (~3.9 Gbps over Ethernet + ~100 Mbps over Wi-Fi). When a higher total load than 4 Gbps was sent over the Ethernet ports plus Wi-Fi, the Wi-Fi traffic had an impact on the Ethernet throughput.
- Setting up 20000 TCP sessions with a pre-scheduled interval of 50 ms did not show any problems. The set-up (handshake) time was on average 10 ms and always below 20 ms. It was observed that the set-up time was above average the first 4000 sessions. After that it stayed nicely around the average.

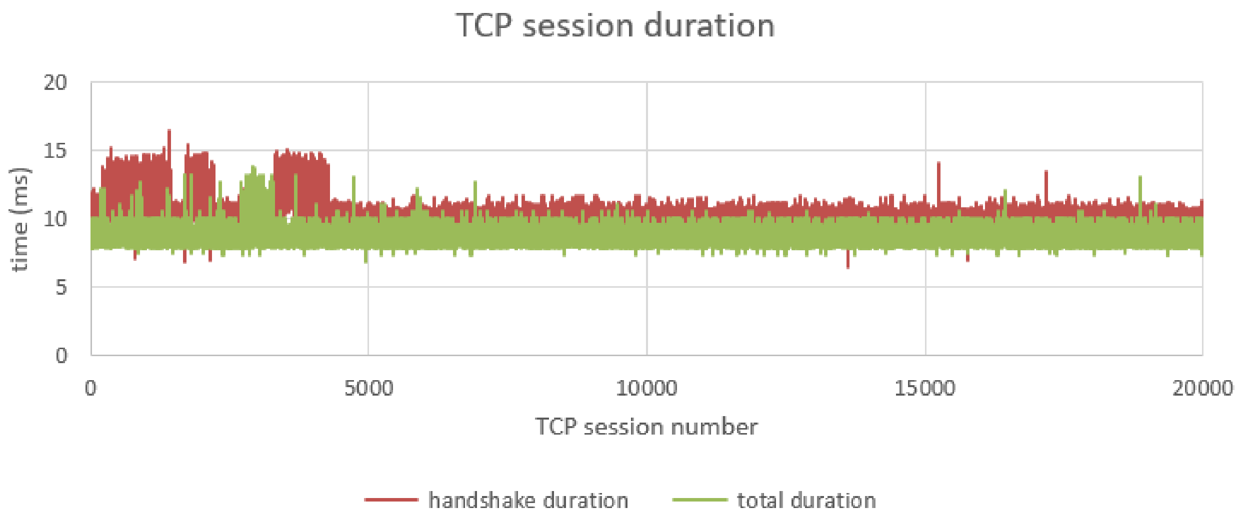


Figure 2: TCP handshake duration is above average for the first 4000 TCP sessions

- The maximum measured throughput values are summarized in the graphs below:

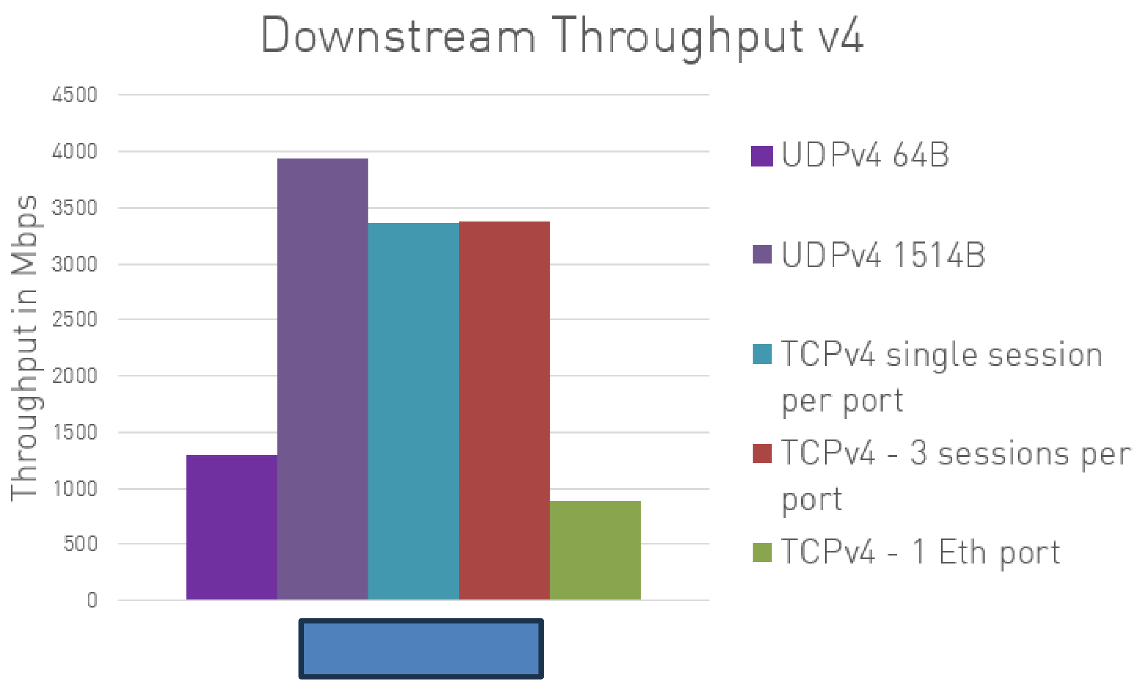


Figure 3: Downstream UDP and TCP throughput over IPv4

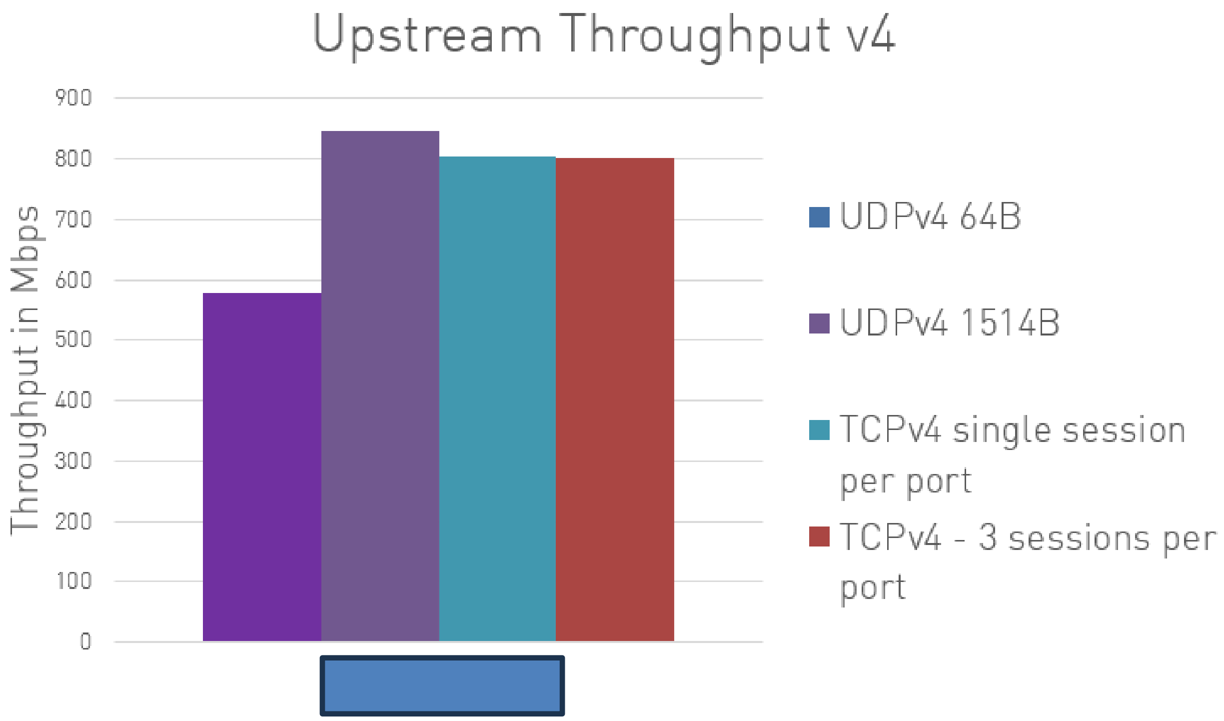


Figure 4: Upstream UDP and TCP throughput IPv4

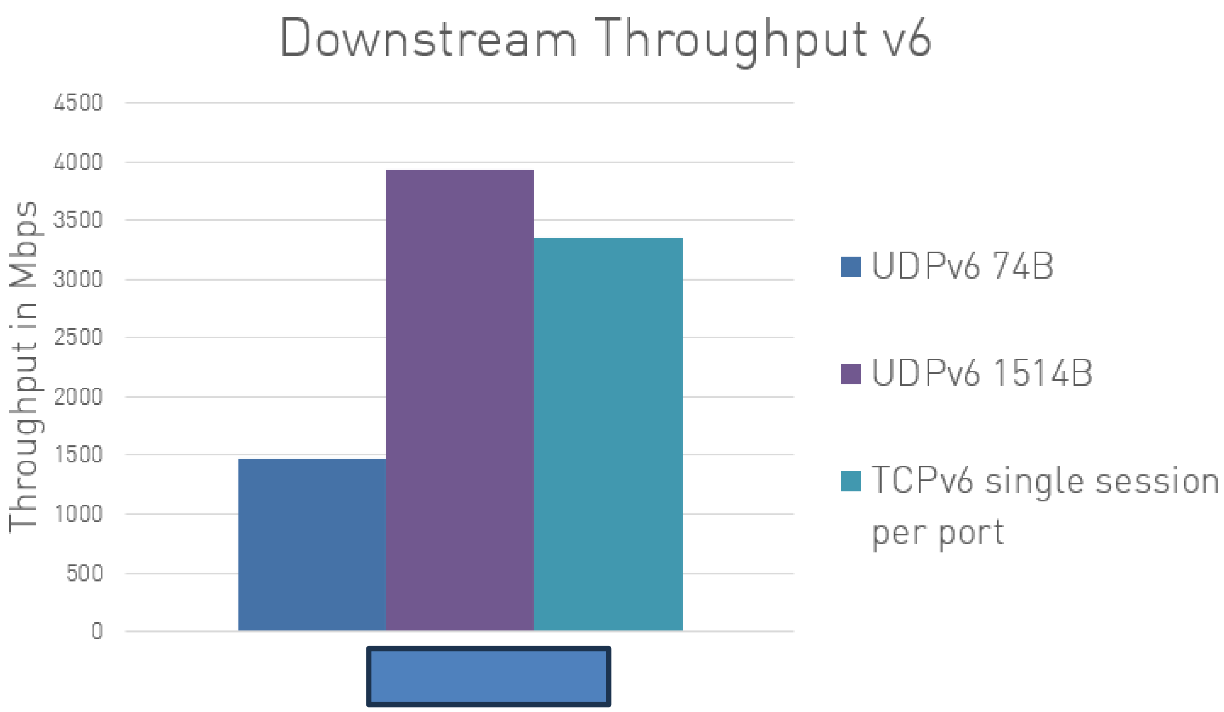


Figure 5: Downstream UDP and TCP throughput IPv6

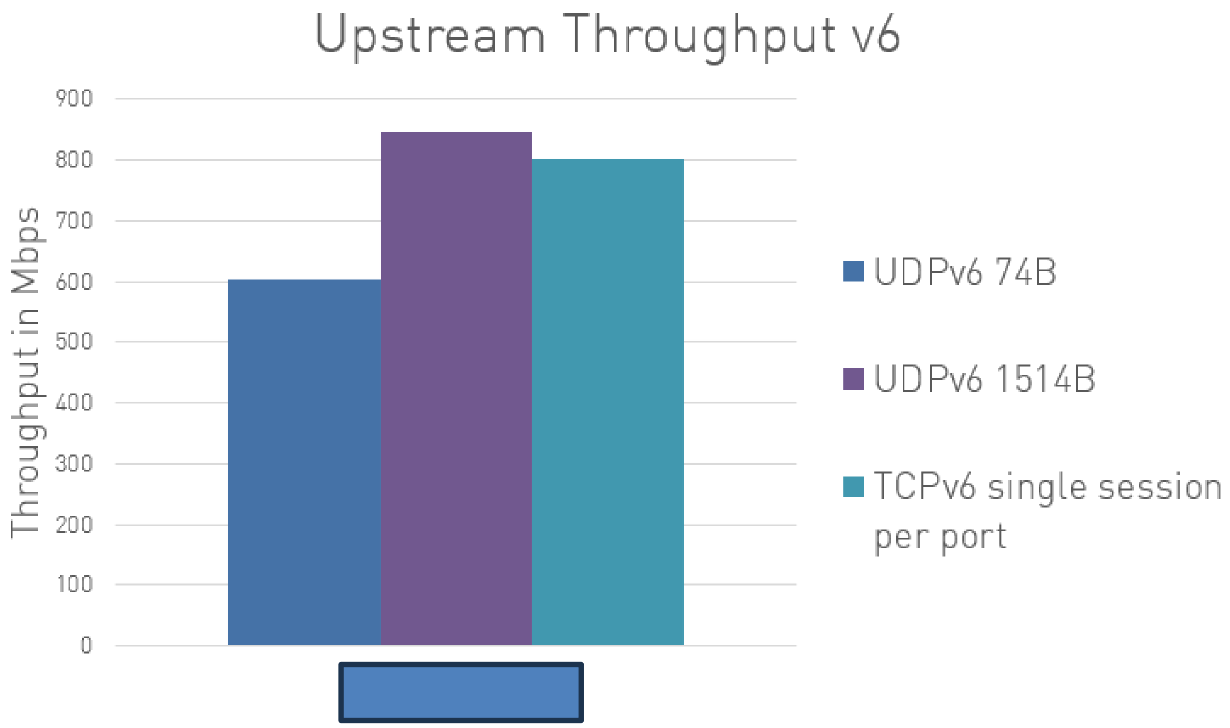


Figure 6: Upstream UDP and TCP throughput IPv6

Remark:

For small packets, it was observed that the downstream throughput collapsed after a few minutes. With only one OFDM channel (instead of two) in the CMTS configuration, this was however not the case. The maximum throughput remained stable for the five-minute test. This was a CMTS issue, because when the maximum load was spread over two modems, they could each separately run the traffic, but combined this was not possible. For this reason, the small-packets downstream throughput test was executed with only one OFDM channel configured on the CMTS. This did not limit the relevant capacity for the modem, as the measured throughput was still well below the RF capacity, even with only one OFDM channel.

3.10 Power Consumption

This test measures the power consumption by the device. This is done in scenarios where stress is gradually increased to the individual components of the device.

This includes:

- Energy Management (EM) mode enabled/disabled
- Ethernet connection and activity
- Telephony connection and activity
- Wi-Fi connections and activity

These components are cumulatively activated, and power consumption is measured over one-minute intervals.

Result: FAIL

The modem did **not** go into **energy management 1x1** mode.

Observations

Scenario	Power consumption
Scenario 1: Modem is online and Energy Management is disabled. The eDVA is online and a phone is connected. Wi-Fi is enabled but there are no associated devices. No Ethernet cable is connected.	14.6 W
Scenario 2: Energy Management is enabled. Other parameters stay the same. The modem did however not enter EM 1x1 mode.	14.6 W
Scenario 3: Transmit 50 Mbps upstream and 500 Mbps downstream over the RF <-> LAN interface.	16.0 W
Scenario 4: Set up a telephone call. Traffic from scenario 3 is still running	17.0 W
Scenario 5: Two Wi-Fi stations are connected, one to each Wi-Fi band (2.4 and 5 GHz). Each client sends and receives 10 Mbps traffic. Traffic and phone call from scenarios 3 and 4 are still running.	17.3 W

Table 3: Modem power consumption in different scenarios

Scenario 2 could not be tested the way it was intended to. The Vendor A modem did not switch to 1x1 operation when energy management was configured to force it to do so.

On the CMTS, energy management was enabled for the MAC domain and the cable modem was provisioned as below:

[redacted]

[redacted]

Other cable modems on the same CMTS MAC domain were configured the same and these entered 1x1 operation when long inactivity was detected. Because of this, the result of this test is FAIL.

3.11 Long Term Loading

This test verifies that the modem remains performant during a longterm twelve-hour test under heavy loading conditions. These conditions involve high traffic loading, high upstream transmit power, high temperature, a high amount of classifiers and a voice call being present.

Result: FAIL

The **modem does not keep forwarding traffic and voice** during the twelve-hour load test.

Observations

During the ramp up of the temperature to 40° C (maximum temperature according to the safety instructions found in the modem box) and the first seven hours, traffic and voice was running smoothly.

After seven hours of performing under heavy loading conditions, the modem reported in its docsDevEventTable:

```
THERMAL THROTTLE:  Temperature 85C, transition to state
EM-RSP received, Reject Permanent
```

At this point a drop of 2.5 dB in OFDMA and ATDMA transmit power was observed in the modem MIBs and voice and traffic problems occurred.

The CMTS reported more than 100 registration flaps and 27 ranging flaps for the modem under load.

When the docsDevEventTable could be read out in between reboots, various mentions of the thermal throttle and EM-RSP messages were seen.

A second sample that was online, but did not have a traffic load, only showed the thermal throttle in its docsDevEventTable. No flaps for this sample were seen.

After cooling down, voice and traffic were again possible as before.

3.12 Wi-Fi maximum throughput

The maximum throughput was measured on four different Wi-Fi clients.

- Samsung S10 (2 spatial streams)

- iPhone 11 (2 spatial streams)
- MacBook Pro (3 spatial streams)
- Dell laptop with Intel Wi-Fi card (2 spatial streams)

The throughput was measured with each Wi-Fi client connected individually, first on the 2.4 GHz band, then on the 5 GHz band.

This was tried at two locations, to increase the chance of finding the maximum throughput. One location was with the devices very near to the access point (1.5 m), the second location with 4 m in between. This specific second location was selected since it is known as the location with traditionally the highest throughput rates.

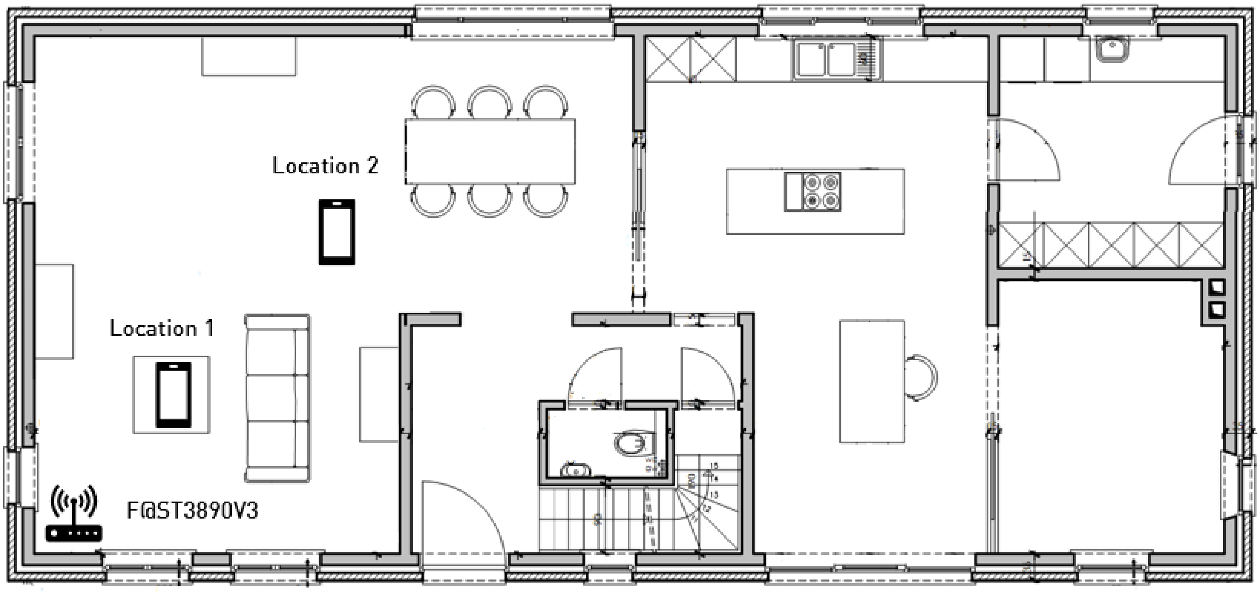
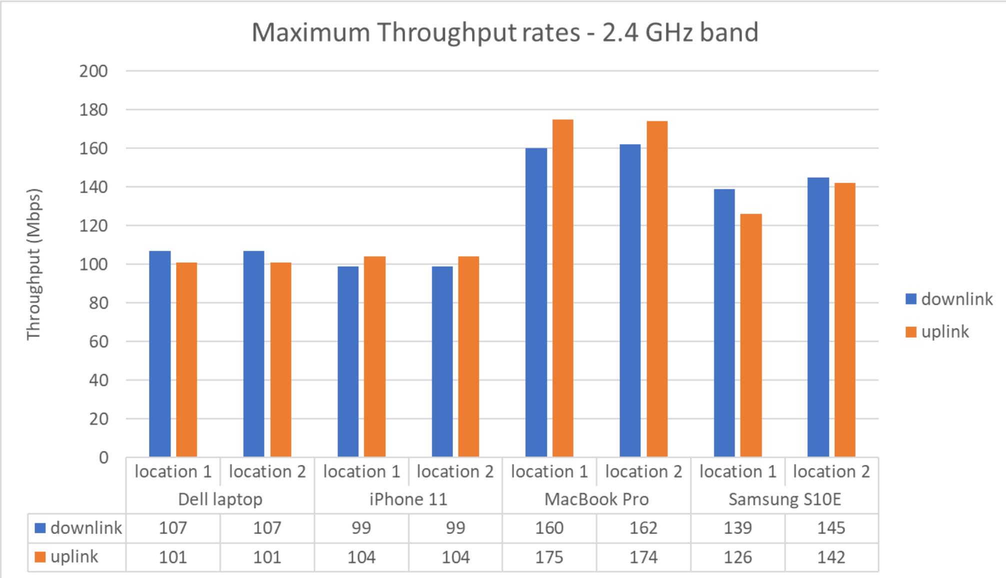


Figure 7: Location of Wi-Fi devices

Wi-Fi was configured as below:

- 2.4 GHz band: Channel 1 – bandwidth 20 MHz
- 5 GHz band: Channel 36 – bandwidth 80 MHz

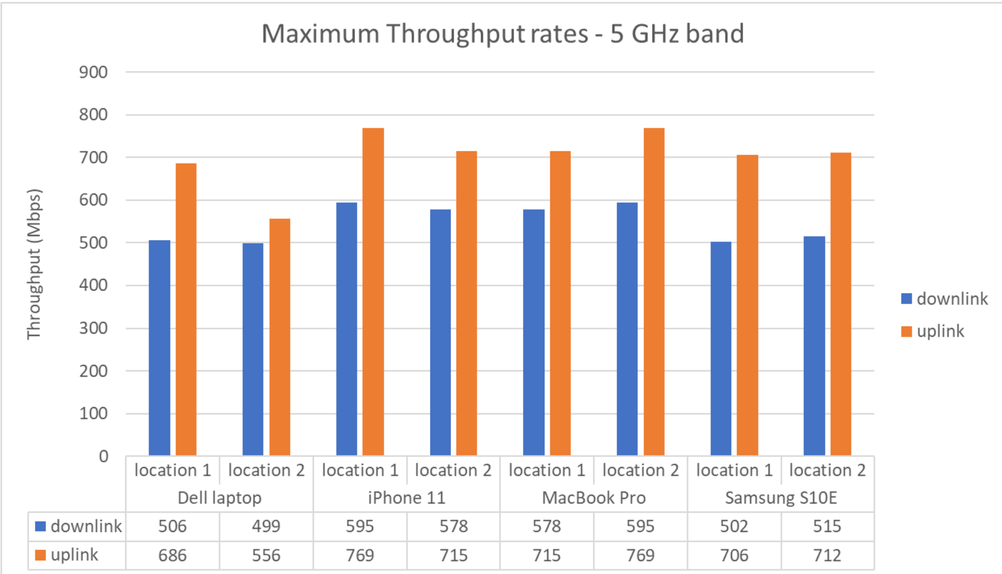
Maximum Wi-Fi throughput rates found in the 2.4 GHz band:



	Dell laptop location 1	Dell laptop location 2	iPhone 11 location 1	iPhone 11 location 2	MacBook Pro location 1	MacBook Pro location 2	Samsung S10E location 1	Samsung S10E location 2
downlink	107	107	99	99	160	162	139	145
uplink	101	101	104	104	175	174	126	142

Figure 8: Maximum throughput rates in the 2.4 GHz band

Maximum throughput rates found in the 5 GHz band:



	Dell laptop location 1	Dell laptop location 2	iPhone 11 location 1	iPhone 11 location 2	MacBook Pro location 1	MacBook Pro location 2	Samsung S10E location 1	Samsung S10E location 2
downlink	506	499	595	578	578	595	502	515
uplink	686	556	769	715	715	769	706	712

Figure 9: Maximum throughput rates in the 5 GHz band

The throughput on all clients is as expected, and very consistent throughout.

4 Software Validation

4.1 Stability Test

This test verifies the operation, stability, and interoperability of the CPE device in a simulated real-life setup. The CPE device and its services must operate in a stable and uninterrupted manner for five days. During this test time, it is made sure the CPE devices remain online and handle periodic network events (like DHCP renewals, BPI+ key exchanges and load balancing) well. Data service is tested by looking at packet loss, data rates and TCP connection failures. Voice service is tested by looking at voice connection failures and dropped calls.
In this test run both CM and CMTS are under validation. The CM analysis is reported below, the CMTS validation is part of another report.

Result: PASS with remark

No major service stability issues are found for this modem on the CMTS VENDOR CMTS. However, on **two of the seven modems**, there was **multicast traffic loss**.

Setup

Modem test conditions

Seven xxxx modems were under test:

- over three different CMTS mac domain configurations
- using two different traffic types (UDP and TCP)
- using SIP VoIP signaling
- with multiple multicast traffic sessions periodically set up to the modems

Following table provides a config overview, more details can be found in the following paragraphs.

CM	CM MAC	DOCSIS Config	Traffic Type
1	[redacted]	Config 1	UDP
2	[redacted]	Config 2	UDP
3	[redacted]	Config 3	UDP
4	[redacted]	Config 4	TCP
5	[redacted]	Config 5	TCP
6	[redacted]	Config 6	TCP
7	[redacted]	Config 6	UDP

Table 4: CM setup overview in stability test

DOCSIS config:

The modems were spread over four mac domains (MD) with different fiber node configurations:

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

For the OFDMA channels a mix of OFDMA profiles, exceptions and exclusions was used.

Further details of the CMTS stability test configuration are added to Appendix A: CMTS Config.

Traffic types:

- UDP IPv4 traffic over four DUTs with two flows per CM:
  - Upstream 512-byte packets at 2000 pps (8 Mbps)
  - Downstream 1024 -byte packets at 5000 pps (40 Mbps)
- TCP traffic over three DUTs:
  Loops of one-hour TCP sessions with random TCP-interval start times between 0 and 120 seconds. These flows ran upstream and downstream and were rate limited within the TCP session (50 Mbps down and 10 Mbps up).

Voice:
The Vendor A eDVA only supported one telephony line and had a SIP stack. All seven modems had voice calls running.

Multicast:
Fifteen multicast flows with a rate of 8.5 Mbps of 1.5 hours with a different source address were periodically set up. The fifteen sessions were spread over the seven modems where each modem did not receive more than three multicast sessions at the same time. Modems on the same mac domain shared one multicast stream. Additionally, a 1 kbps multicast flow with a duration of 24 hours was continuously sent to all seven modems.

Observations

PHY:

The modems had good reception and transmission quality based on the CM and CMTS data.

All modems remained bonded online on 32 downstream channels (one being OFDM) and 7 upstream channels (one being OFDMA) for the duration of the test. No modem flaps were seen.

Traffic results

On all units the UDP loss was below 0.5% in all 300-second measurement intervals. This is considered ok.

The average TCP session speeds over time were for all downstream sessions 50 Mbps and for the upstream sessions 10 Mbps. One modem failed to set up one downstream TCP session.

Two of the seven units suffered loss in the multicast sessions (between 0.5 and 10%). One of these units had only UDP traffic, the other only TCP traffic (next to the multicast traffic). This loss was only observed when data traffic was running as verified after the stability test. No UDP loss was observed and TCP was as expected for both units respectively. For all other samples, no loss was observed for the multicast sessions.

Voice results

Voice calls were successfully set up for the duration of the test. No packet loss was seen for voice traffic and MOS values were above four. It was observed though that the Vendor A units made use of voice activity detection and generated comfort noise (as a default setting) while the reference Vendor B units did not generate comfort noise. It would be advised to straighten this inconsistency. During the test it was also observed that the Excentis Asterisk based SIP server did not support comfort noise packets and discarded those, resulting in bad statistics in [redacted]. By disabling comfort noise generation on the EDVA using the sipEndPntConfigUserVADMode MIB, no downstream packet loss was reported anymore. This downstream packet loss reporting was however not a modem issue but related to the SIP server in use.

Detailed monitoring

Detailed monitoring of the CM/CMTS 3.0&3.1 MIBs did not show any issues.

The assigned OFDM and OFDMA profiles per modem were never demoted during the test.

4.2 Monitoring

The goal of this test is to verify the basic interoperability of VoIPexaminer and MONITORING TOOL2 with the CMs and MTAs used by Customer.

Result: PASS

VoIPexaminer and MONITORING TOOL2 are interoperable with the CMs and MTAs.

Observations

VoIPexaminer

Cooperation with the MTAs used by Customer was successfully verified. [redacted] successfully retrieved all relevant information from the MTAs.

Monitoring system

Cooperation with the modems used by Customer was verified.

During the stability test, the "hanging service flow" component was verified as well. Calls were made using an Asterisk agent and no hanging service flows were detected during this test.

One minor issue was detected:

- The partial service list in Monitoring tool was not always complete (sometimes more partial service modems were seen in the CLI of the CMTS than in MONITORING TOOL2). The reason was that SNMP failed (due to high traffic load) to these modems in partial service, so the partial service state could not be verified by the monitoring system.

4.3 TCP Subscription Speeds

This service rate compliance test determines whether the current or near-future TCP maximum subscription speed rates can be offered in a stable way. Both IPv4 and IPv6 service is covered. In all these cases TCP throughput similar to a speed test is measured, but over a period of 5 minutes. It is also verified whether the Round trip Time is within limits.

Result: PASS

The modem was able to deliver the defined subscription speed rates.

Observations

In the table below, the measured TCP throughput values are shown when using a 1500 Mbit/s downstream rate limit and a 200 Mbit/s upstream rate limit in the CM configuration file (as provided by Customer).

The modem was bonding 31 SC-QAM + 1 OFDM 192 MHz (2K QAM profile) downstreams and 6 SC-QAM ATDMA + 1 OFDMA 48 MHz (64 QAM profile) upstreams.

Test	TCP Throughput [Mbit/s]	Expected TCP Throughput*[Mbit/s]	RTT Avg [ms]
Downstream – Ipv4 – 2 sessions – 2 Eth ports	1389	1423	40
Downstream – Ipv4 – 10 sessions – 2 Eth ports	1435	1423	200
Downstream – Ipv6 – 10 sessions – 2 Eth ports	1399	1405	200
Downstream & upstream – Ipv4 – 4 sessions each – 2 Eth ports	1429 & 180	1423 & 190	200 & 200
Upstream – Ipv4 – 1 session	190	190	20
Upstream – Ipv4 – 10 sessions – 2 Eth ports	192	190	20
Upstream – Ipv6 – 10 sessions – 2 Eth ports	190	187	20
* Expected throughput is calculated by subtracting the layer-2 overhead from the configured rate limits.			

Table 5: CMTS subscription speeds and round-trip times

The maximum RTT was always lower than 250 ms. This is well below 1 s, so no severe service impact is expected. The average RTT was between 20 and 200 ms, which is slightly higher than observed during previous test campaigns. During this test campaign however, throughput rates were also higher than in earlier runs. Also note here that AQM was enabled for the modem (as this is by default the case).

The test with a single upstream TCP flow was repeated with AQM disabled. The throughput stayed the same but average RTT went up from 20 to 100 ms. This is a normal and expected increase in RTT when AQM is disabled.

4.4 Partial Service ED3.0 & D3.1

This test verifies if the CM behaves correctly regarding partial service in a mixed EuroDOCSIS 3.0 and DOCSIS 3.1 environment. One or more RF channels is disturbed by adding sufficient noise to make the channel(s) unusable for the CM. Eventually the channel connection is restored so the modem can start using it again.

Result: PASS with remark

The modem behaves correctly in the tested scenarios. It does however **not send a QAM-FEC lock loss/recovery CM-STATUS** message when an **OFDM channel** is interfered. Currently this has **no operational impact**, as the CMTS does not need this message to put the modem into partial service.

Observations

Partial service when registering

The CM got correctly online in partial service in all tested scenarios: with one ATDMA upstream channel impaired, with a primary OFDM downstream channel impaired and with an OFDMA upstream together with a SC-QAM downstream and a non-primary OFDM downstream channel impaired.

When the channels were available again, data could be sent and received on all channels.

However, it was observed when recovering an OFDM downstream channel, this was done by the CMTS based on CM-STATUS messages indicating PLC recovery, NCP recovery and OFDM profile recovery. No QAM/FEC lock recovery message was seen while this is expected from the modem. Since the CMTS did not wait for this message, this did not negatively influence the test outcome.

Partial service during operational state while having a voice call

In all scenarios (except the scenario with OFDM backup, which was not executed since this is not supported yet by the CMTS VENDOR CMTS) the CM went correctly into partial service as expected. Voice calls stayed up, unless they were running on the impaired channel. In this case, it was possible to set up the voice call again. When the channels became available again, data was sent and received on all available channels.

During this scenario as well, it was observed that the CM sent no QAM/FEC lock loss or recovery message for an OFDM channel. Since the CMTS did not wait for this message, this did not negatively influence the test outcome.

4.5 OFDM Profile Management

This test verifies the OFDM downstream profile promotion and demotion functionality on the CM, together with the partial channel reporting. An OFDM channel will be disturbed so that some of the assigned profiles within an OFDM channel become unusable by the CM. The CM must report this event (loss of profile) to the CMTS and based on this the CMTS can switch to a lower profile. The CM must be able to forward data on these profiles and continue forwarding after a profile switch. Afterwards the channel is restored to normal connection again.

Result: FAIL

Profile demotion and promotion works as expected on the modem; however the **CM does not report** the **loss of the PLC** of a non-primary OFDM downstream with a CM-STATUS message. Also after reporting **NCP recovery**, the modem immediately sends an **OFDM profile recovery** message, resulting in unwanted profile recoveries and consequent traffic loss.

Observations

When the PLC of the non-primary OFDM downstream channel was disturbed, the modem did not send a CM-STATUS message to the CMTS to report this. As a result, the OFDM channel kept being used to send data to the modem. Even with a flow of 100 Mbps, which does not exceed the capacity without using the OFDM channel, this resulted in traffic loss.

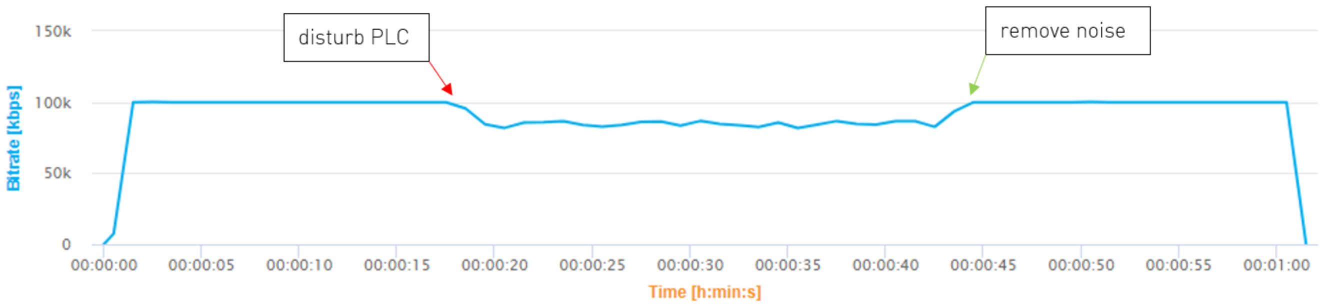


Figure 10: Traffic loss on a 100 Mbps stream due to not sending PLC failure CM-STATUS message

When the CM lost profiles one by one and regained them afterwards, or the CM lost all profiles at once, the correct CM-STATUS messages were sent, and data traffic was as expected for the profiles in use. Also when registering on the lowest profile and regaining the higher profiles later on, the behavior was as expected.

As an extra check, also the lowest profile of the OFDM channel was disturbed by adding noise. The CM correctly reported the loss of the OFDM profile with a CM-STATUS message. It was observed however, by adding more noise so the NCP was also disturbed, that the modem sent CM-STATUS messages with 'NCP recovery' immediately followed by 'OFDM profile recovery'. This resulted in data loss, since the CMTS assumed it could use the OFDM downstream channel again while it was still disturbed. Even with a 100 Mbps downstream flow, up to 30% loss was observed. When the modem then sent another CM-STATUS message to report the loss of the lowest profile, traffic was regained, but NCP recovery messages followed by incorrect OFDM profile recovery messages were kept being sent.

It should also be noted that the NCP-failure messages were not sent consistently.

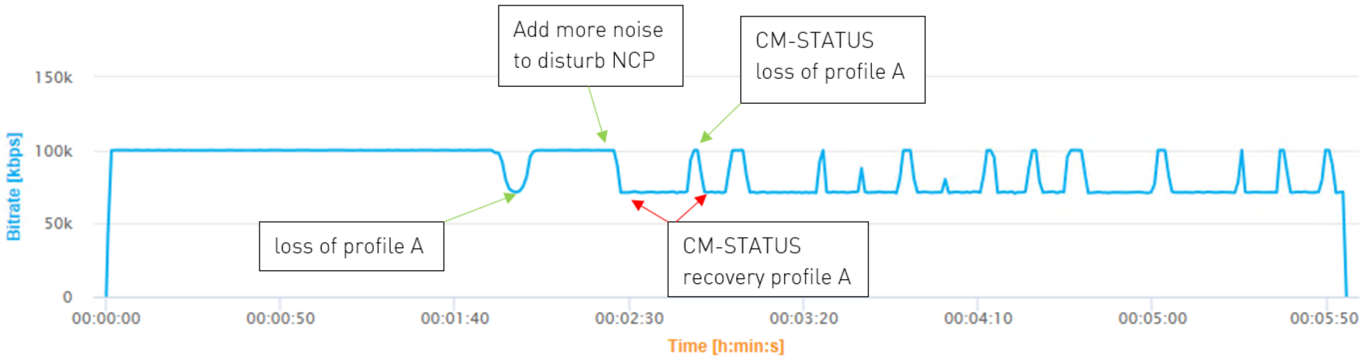


Figure 11: Traffic loss on a 100 Mbps stream due to incorrect sending of OFDM profile recovery CM-STATUS message

4.6 OFDM/OFDMA Mixed Modulations and Exclusions

This test verifies that the CM can handle an OFDM downstream and OFDMA upstream channel with mixed modulation (variable bit loading) and exclusions. An OFDM and OFDMA channel are configured for different scenarios of mixed profiles, and exclusions are added inside the OFDM and OFDMA channels. By sending traffic (15 min) over the channels each time it is verified that the modem can still use these OFDM and OFDMA channels correctly.

Result: PASS

The modem works as expected when using an OFDMA and OFDM channel with mixed modulation and exclusions.

Observations

On the OFDMA and OFDM channel different scenarios of mixed modulation and exclusions were applied. The CMTS supported for the OFDM channel up to five exception zones per profile and up to ten exclusion zones could be configured for this test. On an OFDMA channel the CMTS supported up to four exception zones and eight exclusion zones according to the manual. The modem has been tested on a channel with these maxima of configurations. For all tested configurations, the CM behaved as expected.

Some example CMTS configuration lines for these settings are given below:

[redacted]

[redacted]

[redacted]

[redacted]

4.7 OFDMA Profile Management

This test verifies that the CM reacts well to OFDMA profile switches. The CM must cooperate with the CMTS regarding DOCSIS 3.1 profile management operations.

Result: FAIL

While the modem correctly follows the directives of the CMTS in most tested situations, it **cannot successfully recover an OFDMA profile after it registered with an interfered OFDMA** upstream channel.

Observations

On the latest CMTS vendor CMTS VENDOR software up to seven OFDMA IUC profiles can be configured on an OFDMA upstream channel. The modem can only have two different profiles at any given time, so to change between the seven profiles, the CMTS had to make use of Dynamic Bonding Change (DBC) messages. This mechanism has been verified and worked as expected.

Three different scenarios were tested:

- CM loses profiles one by one when it is operational and recovers them:
  The modem correctly followed the profile changes directed by the CMTS. For each profile change that required a DBC message, the CMTS-CM shortly (a few seconds) switched to IUC 13, to change the second profile of the modem, and then the updated IUC could be used.

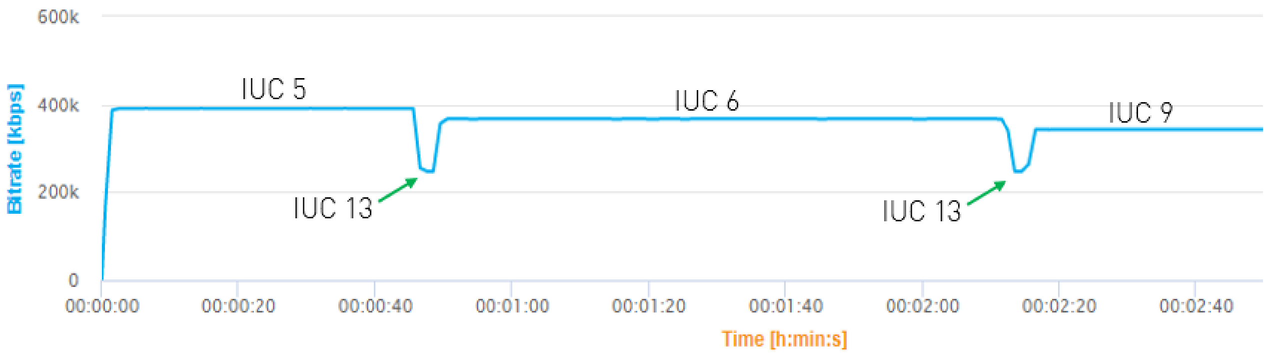


Figure 12: Throughput during loss of two OFDMA profiles

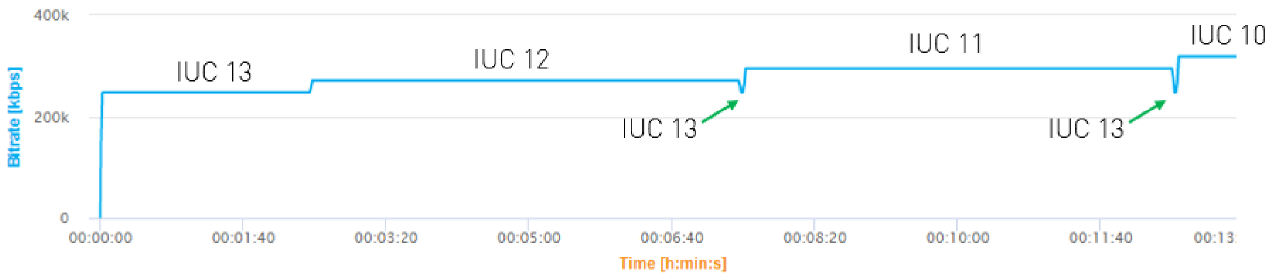


Figure 13: Throughput during recovery of three OFDMA profiles

- CM loses multiple profiles at once when it is operational and recovers them:
  When the SNR was abruptly decreased by adding noise, the CMTS did not switch to the lowest OFDMA profile, but instead brought the OFDMA upstream channel into partial service. While the noise remained present, after approximately five minutes, the CMTS considered the channel usable, and the modem correctly started using the lowest modulation IUC profile (13). About five minutes after the noise was removed, the highest

modulation IUC profile (5) was recovered and used for upstream data transmission.

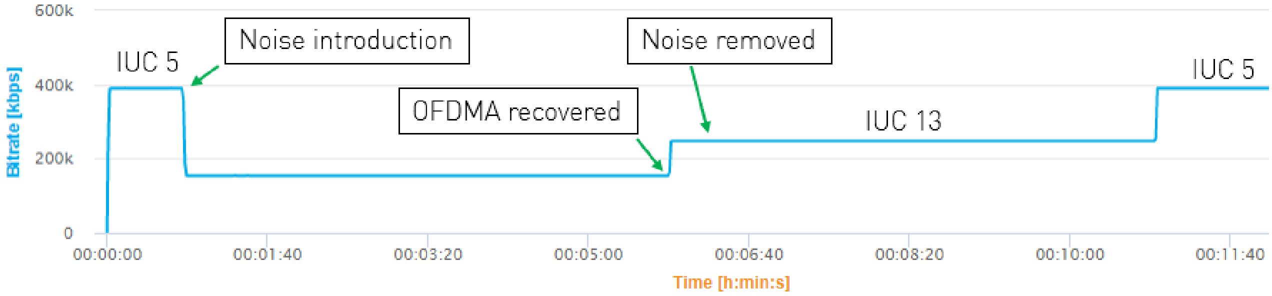


Figure 14: Throughput during abrupt loss and recovery of multiple OFDMA profiles

- <u>CM recovers profile which was impaired at registration</u>:
  When the modem was booted with upstream interference in such a way that only IUC profile 13 could be used, the CMTS and modem successfully used IUC 13. After the noise was removed, the CMTS triggered the addition of a higher profile with DBC, but the CM rejected the message and went offline. The modem should accept the DBC message however and remain online with the higher IUC profile. In the CMTS logging the following was reported:

  [redacted]

  [redacted]

  [redacted]

  [redacted]

4.8 Airtime Fairness (Point-to-multipoint throughput)

The airtime fairness is one of the Wi-Fi KPIs that indicates how well the Wi-Fi access point can handle multiple connected clients simultaneously. The access point must divide the available airtime so that each Wi-Fi client gets a proper proportion. Ideally, there is an equal distribution of the airtime. In practice, the main concern is to see that no Wi-Fi client gets 'starved', i.e. gets almost no airtime at all.

Result: FAIL

The **airtime was not fairly distributed** between the different clients.

Observations

To test the fair distribution of airtime, the following setup was created:

- Three Wi-Fi clients connected to 5 GHz band, in three different rooms
- Three Wi-Fi clients connected to 2.4 GHz band, spread over the same rooms.

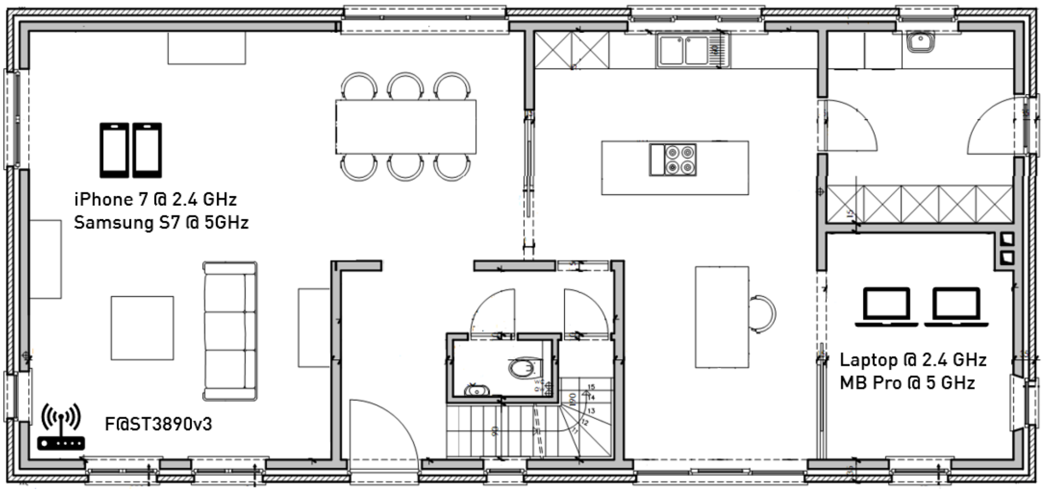


Figure 15: Downstairs device positioning

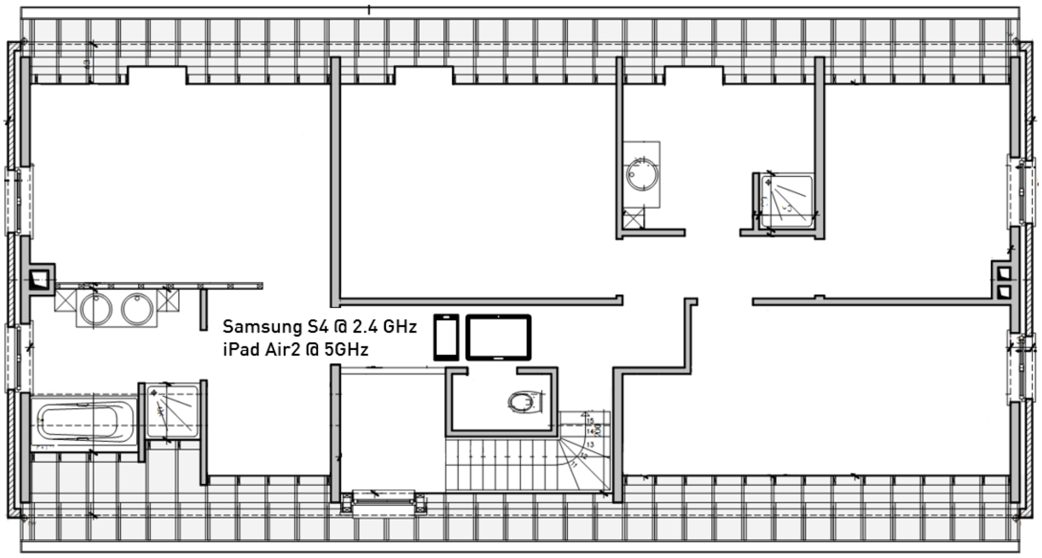


Figure 16: Upstairs device locations

Test per room – no airtime distribution needed

Per room, there are two Wi-Fi clients, one of which is connected to the 2.4 GHz band and the other to the 5 GHz band. These devices can send and receive simultaneously, because they are on different bands.

The graph below shows the traffic rates when the Wi-Fi clients were receiving or transmitting individually (blue bars), versus when they were sending or receiving in pairs (orange bars), per location.

- iPhone 7 on 2.4 GHz was paired with Samsung S7 on 5 GHz
- Dell laptop on 2.4 GHz was paired with MacBook Pro on 5 GHz
- Samsung S4 on 2.4 GHz was paired with iPad Air 2 on 5 GHz

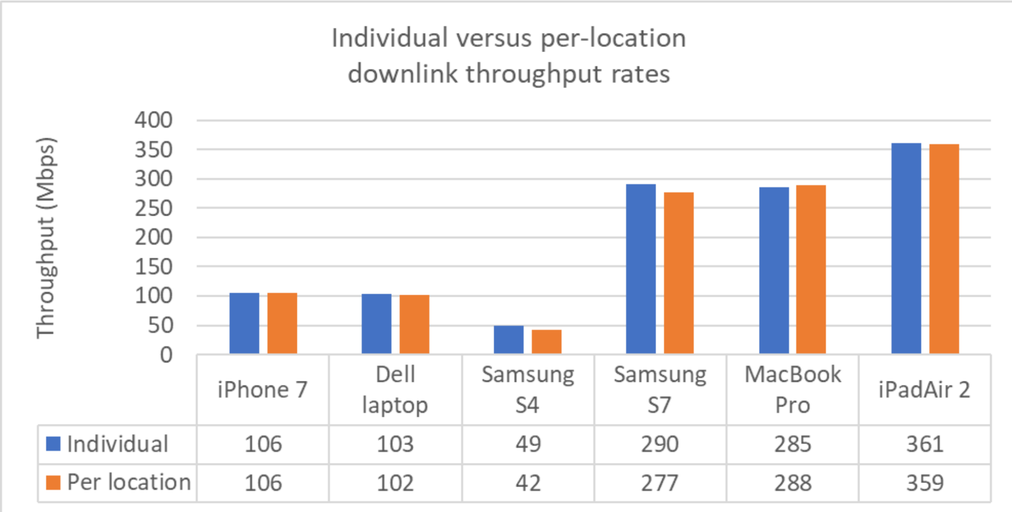


Figure 17: No influence between 2.4 and 5 GHz band with downlink traffic

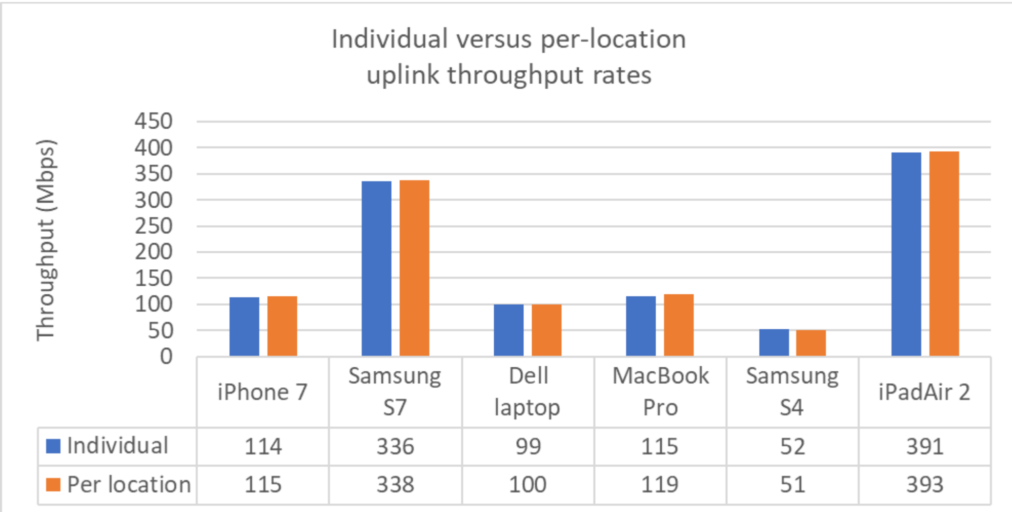


Figure 18: No influence between 2.4 and 5 GHz band with uplink traffic

As expected, there was no interference when devices on different bands were sending or receiving traffic simultaneously.

Test per Wi-Fi band – airtime distribution needed

The graphs below show the simultaneous traffic rates when airtime needed to be shared over three devices per band. Ideally, each device would get 30 % of the available airtime.

The red line in the graph shows what proportion of airtime the Wi-Fi client got. This was calculated by dividing the shared-airtime throughput with the individual throughput.

The first graph below shows downlink airtime distribution. There is a large difference between the 2.4 GHz band and the 5 GHz band:

- 2.4 GHz band: very good airtime distribution
- 5 GHz band: bad distribution, airtime mainly goes to one single client.

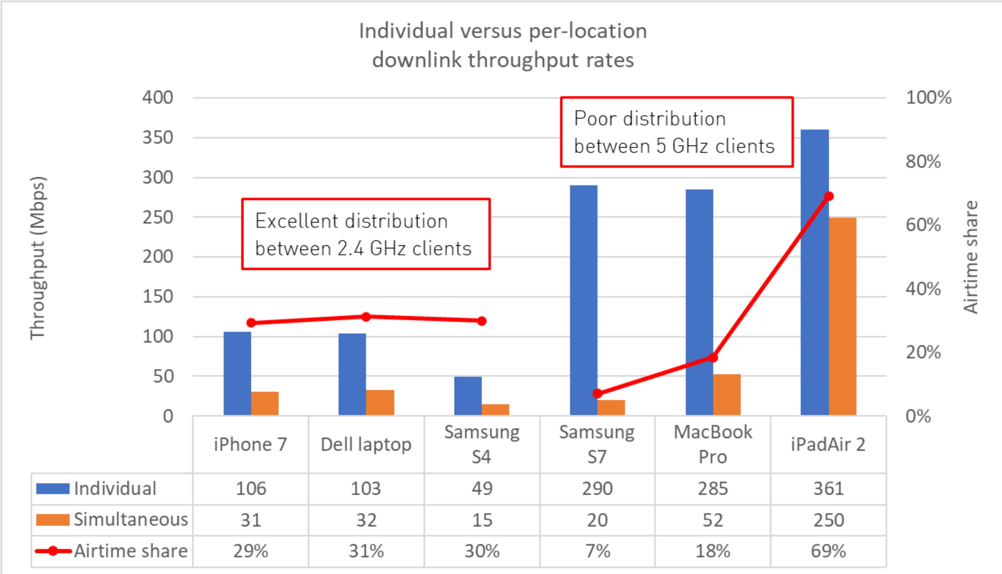


Figure 19: Downlink airtime is only distributed fairly in the 2.4 GHz band

In the uplink, it is apparent that airtime was taken mainly by the devices that were nearby and remaining airtime dropped quickly with decreasing RSSI.

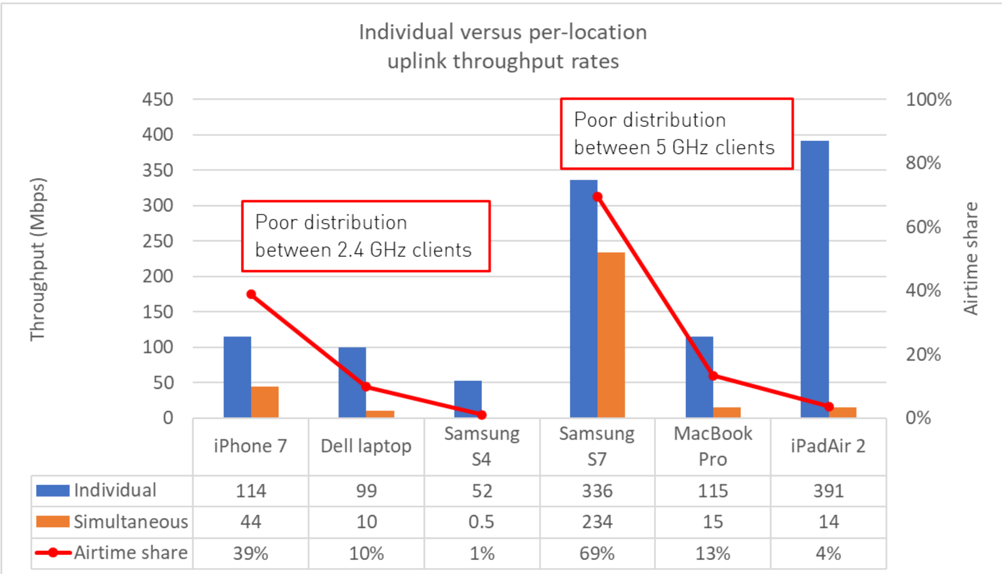


Figure 20: Uplink airtime is given mainly to near devices

The Wi-Fi gateway is completely in control of downlink airtime distribution, but not in the uplink. It is not uncommon to see different behavior in downlink versus uplink.

Test item	Result
Downlink – no interference between 2.4 and 5 GHz band	PASS
Downlink – fair airtime distribution on 2.4 GHz band	PASS
Downlink – fair airtime distribution on 5 GHz band	FAIL
Uplink – no interference between 2.4 and 5 GHz	PASS
Uplink – fair airtime distribution on 2.4 GHz band	FAIL

Uplink – fair airtime distribution on 5 GHz band	FAIL

Table 6: Airtime fairness test scenario results

4.9 Neighboring APs - Congestion Testing (co-channel)

Congestion testing happens by letting the Vendor A compete in a fair way with a second access point. Both access points send unlimited TCP flows. In the ideal situation, they both agree on 50 % usage each. This results in interfered throughput that is half of the clear-spectrum throughput.

Result: FAIL

The **neighboring interferer had a higher than allowed on multiple locations**.

Observations

The interferer access point was located in the garden shed, to represent realistic neighbor Wi-Fi power levels.

the MacBook Pro was connected to the Vendor A and tested on the same three locations as used in the airtime fairness test.

The graph below shows how the Vendor A handled the interference on the 2.4 GHz band. On the nearest location (lounge) the result was good, but on the far locations, downlink and uplink dropped down to very low levels.

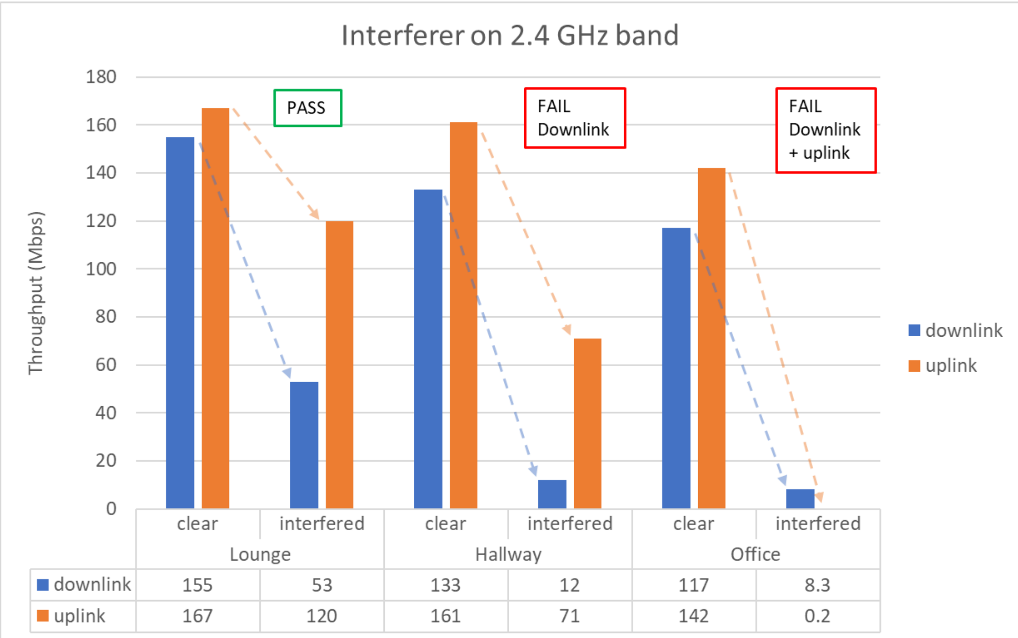


Figure 21: Interference is only handled well in lounge

In the 5 GHz band (see graph below) the results were better than on the 2.4 GHz band. Still, throughput dropped completely under interference on the furthest location.

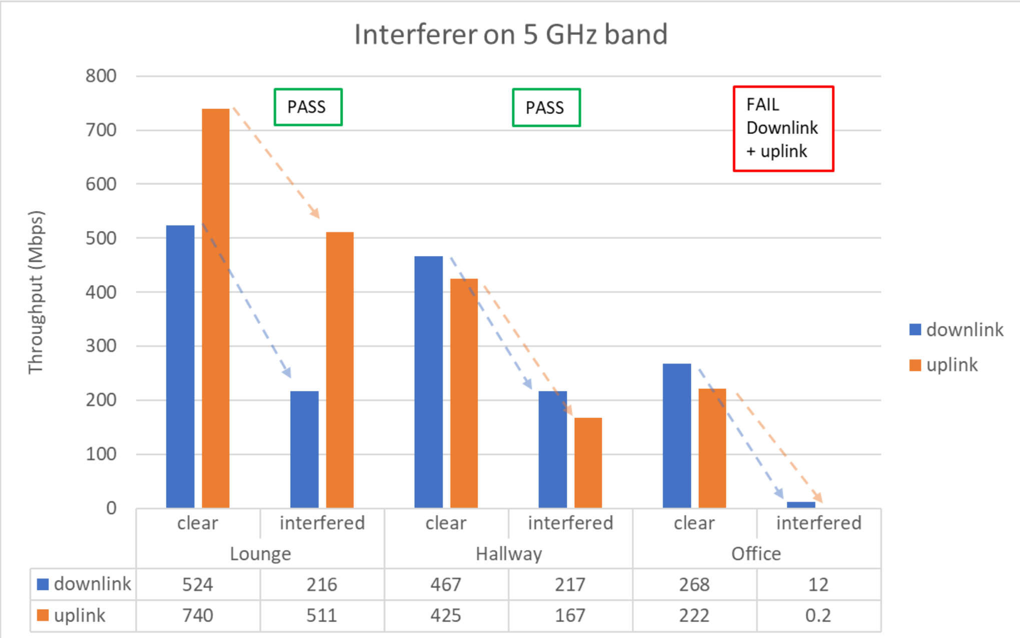


Figure 22: Interference is handled badly on the furthest location

While a fail, these results are not uncommon on APs.

4.10 Wi-Fi Band Steering

Band steering is a Wi-Fi technique that is used to provide the best possible Wi-Fi connection to moving devices. It allows a Wi-Fi access point and client to switch dynamically between the 2.4 GHz and 5 GHz band. Depending on signal strength and quality, the optimal band is chosen.

In the ideal situation, a band steering occurs from the 5 GHz to the 2.4 GHz band when the client device is moving away from the access point, at the moment 5 GHz throughput drops below 2.4 GHz throughput. The switch from 2.4 to 5 GHz ideally occurs when the reverse is true when the client is moving towards the access point.

Result: FAIL

While the band switch was at almost the exact optimal location from the 5 GHz band to the 2.4 GHz band, the **band steering did not happen from 2.4 GHz back to 5 GHz**.

Observations

To verify proper Wi-Fi band steering, the following actions were performed:

- Find the ideal location where a band switch should occur
- Find the actual location where the band switch did occur

This test was run using a Samsung S10E, which supports the 802.11k,v functionality which is crucial for band steering.

First, to find the location where the ideal band switch should occur, the S10E was connected to either band with band steering disabled. Two rate-versus-range measurements -one on each band- were performed.

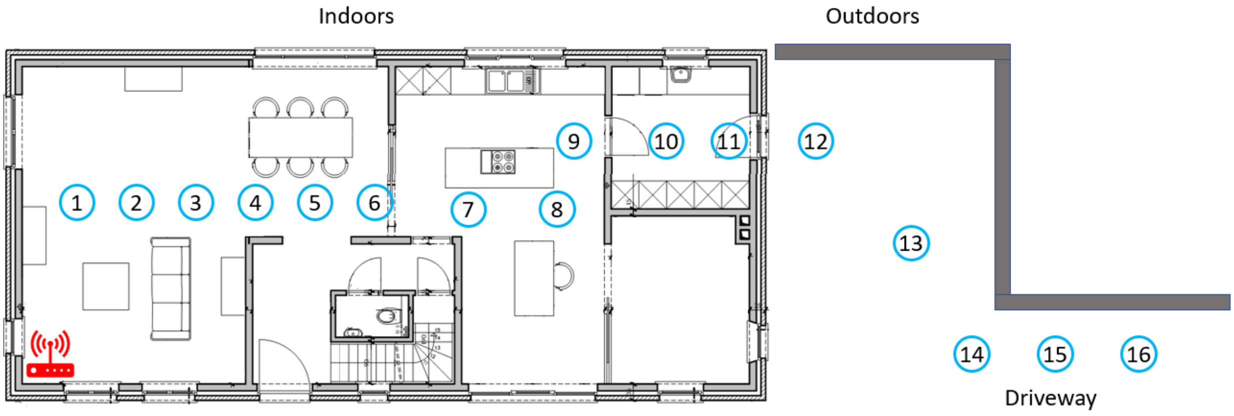


Figure 23: Progressively more distant locations to trigger band steering.

The result from this is shown in the graph below. The 5 GHz band and 2.4 GHz band lines cross between location 13 and 14, so this was the ideal place for band steering. Note that from location 15, the 5 GHz connection was lost, which was expected.

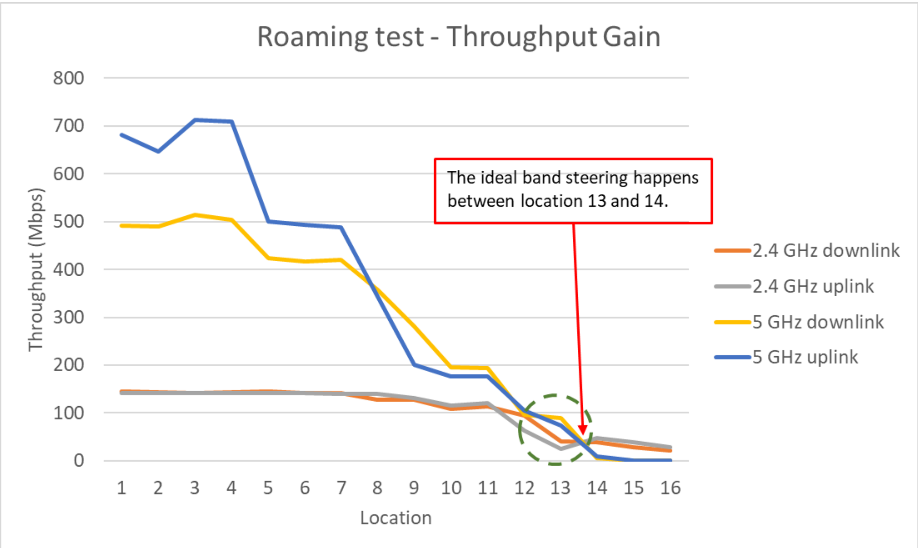


Figure 24: Ideal steering location. Green circle area is enlarged in graph below

Band steering was then enabled, and the test was repeated in two different scenarios:

Starting on location 1, the device was connected to the 5 GHz band and moved away from the access point. We found that the band switch happened between location 12 and 13. Although this means a local drop of 50 Mbps, this is still very close to the ideal location. While this specific band switch could have been a client-based decision, or an AP steering event, it definitely happened around the optimal location.

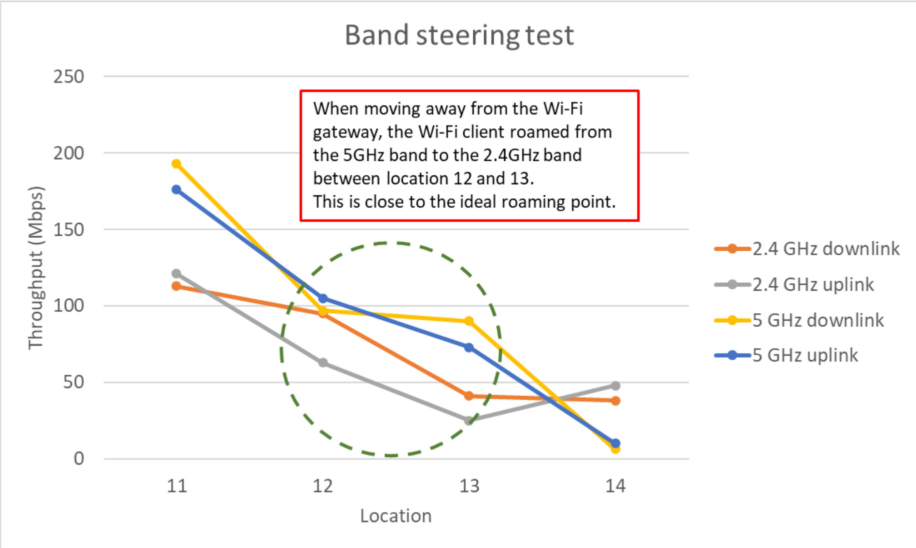


Figure 25: Small throughput loss when roaming between locations 12 and 13

Finally, in the second scenario the client is started on location 16 with the client connected to the 2.4 GHz band. When moving progressively closer to the access point, all the way up to location 1, the client never left the 2.4 GHz band. This 'sticky client behavior' is a common problem.

Test item	Result
Band switch from 5 GHz to 2.4 GHz band	PASS
Band switch from 2.4 GHz to 5 GHz band	FAIL

Table 7: Wi-Fi band steering test scenario results

4.11 L2VPN forwarding

In this test the basic forwarding in a L2VPN configuration is verified, this for downstream and upstream, unicast, multicast and broadcast packets.

Result: FAIL

The **modem** does **not forward broadcast** packets in the **downstream** direction.

Observations

To run this test, the following configuration steps were taken:

- The modem was configured in bridged mode
- Basic L2VPN configuration was added to the CM config file:
  - SF additions
  - Classifier additions
- The necessary CMTS config was done

Basic forwarding includes the upstream and downstream forwarding of unicast, multicast and broadcast packets. This was tested with growing frame sizes at low transmission rates (100 frames per second).

Test item	Result	
	Downstream	Upstream
Unicast packets	PASS	PASS
Multicast packets	PASS	PASS
Broadcast packets	FAIL	PASS

Table 8: L2VPN forwarding results

The Vendor A modem did not forward broadcast packets in the downstream direction in the L2VPN network. These packets had the following characteristics:

- Destination MAC address FFFF:FFFF:FFFF
- Destination IP address 255.255.255.255

The L2VPN network operated in a 10.11.12.0/24 network. The test was repeated with broadcast address 10.11.12.255. These packets were also not forwarded downstream.

To investigate the cause of the issue (modem or CMTS) the test was run on a reference modem as well. On this reference modem the test passed, so it was concluded that the Vendor A unit was the cause.

Dropped broadcast packets can have a large negative impact, specifically (but not limited to) the ARP packets in the L2VPN network.

4.12 TOS Classification

The distinction between L2VPN and non-L2VPN "regular" traffic can happen via classification on the TOS field of traffic. This test verifies this filtering.

Result: PASS

The modem successfully classifies the traffic.

Observations

The filtering is configured for the modem with the addition below in the CM config file:

```
Upstream Packet Classification Encoding
  Classifier Reference:2
  Service Flow Reference:2
  Rule Priority:0
  Classifier Activation State:on
  IP Packet Classification Encodings
    IP Type of Service Range and Mask:       tos-low 0x54
                                             tos-high 0x56 tos-mask 0xFF
```

Two upstream traffic flows were sent, only one of them matched the TOS classifier and must be forwarded. The modem correctly forwarded and dropped the respective packets.

Test item	Result

Packets that match the TOS classifier are forwarded on L2VPN network	PASS
Packets that do not match the classifier are not forwarded on L2VPN network	PASS

Table 9: TOS classification results

4.13 DUT filtering

Broadcast and multicast traffic are normally not encrypted on the downstream and are forwarded by the CM to all customer interfaces and the internal stack. For L2VPN enabled CMs this will result in non-L2VPN traffic (broadcast/multicast) to be injected in the L2VPN (non-L2VPN leakage).
To avoid this, DUT (Downstream Unencrypted Traffic) filtering is defined.

If enabled, unencrypted downstream traffic will only be forwarded to internal interfaces, not to the client side L2VPN. This test verifies that DUT filtering works as expected.

Result: FAIL

Unencrypted downstream packets are forwarded to the CPE in the opposite way they are supposed to. They are **forwarded when not allowed** and **dropped when they must be forwarded**.

Observations

The broadcast packets in this test were generated by pinging a non-existing IP-address in the non-L2VPN IP-range. Pinging first causes broadcast ARP packets to be sent. These must be dropped with DUT control on and forwarded with DUT control off.

CM configuration	Expectation	Observation
`Downstream Unencrypted Traffic Filtering` `DUT Control:on`	Packets dropped	Packets forwarded
`Downstream Unencrypted Traffic Filtering` `DUT Control:off`	Packets forwarded	Packets dropped

Table 10: DUT filtering test results

5 Other Issues and Observations

5.1 MIB OID not correct for docsIf31CmUsOfdmaMinislotCfgStateTable

During testing it was observed that the Vendor A modem did not report the upstream OFDMA minislot configuration as required in the docsIf31CmUsOfdmaMinislotCfgStateTable. More specifically the OID is not built up correctly for the values of this MIB table. The UsOfdmaMinislotCfgState Object as described in the DOCSIS OSSI specification, assigns the StartMinislotNum as last number of the OID, and this key must have a value from 1 to 237. The modem however uses 0 for this value.

This means that in a standard configuration with one minislot configuration, the MIB with for example OID docsIf31CmUsOfdmaMinislotCfgStateFirstSubcarrierId.4.13.1 does not exist, but instead the value corresponding with this MIB is stored in the 4.13.0 OID.

Appendix A: CMTS Config

[redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]
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