6LoWPAN Plugtests;
Berlin, Germany;
27 - 28 July 2013

ETSI

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1 Executive Summary

ETSI organised the first 6LoWPAN (IPv6 over Low power Wireless Personal Area Networks) Interop event (Plugtests) in Berlin, Germany on 27 and 28 July 2013 with the support of IPSO Alliance, FP7 PROBE-IT and IPv6 Forum. This event was co-located with the 87th IETF meeting (28 July - 02 August 2013).

This Plugtests event conducted a testing campaign based on the test cases developed by the ETSI, IPSO Alliance, FP7 PROBE-IT and IPV6 Forum and focused on the interoperability of the IETF 6LoWPAN standards.

The 6LoWPAN protocol is a key component in building the future “Internet of Things” where smart objects become IP enabled and form an integral part of the Internet. This Plugtests event assessed the interoperability of different 6LoWPAN implementations focusing on Header Compression (RFC 6282), Neighbor Discovery (RFC 6775) and Frame Format (RFC 4944).

The event was supported by 15 companies/organizations including partners, university and vendors, providing Host, 6LR or 6LBR routers, and sniffers. Co-locating the interoperability event with IETF has allowed synergy, as some participants attended both. It has been the opportunity to initiate technical discussion and feedback to standardization, especially the 6LoWPAN IETF WG and its potential successor WG 6Lo.

The conclusions are that

- all implementations have been compatible on a basic level.
- The Neighbor Discovery tests were not performed, which was not expected. Several reasons could explain this but it is an indication that the RFC may not be fully implemented by the 6LoWPAN community yet. This information has been provided to IETF 6LoWPAN WG.

In conclusion, 6LoWPAN standard implementation is mature on the packet format and header compression level but a lot of implementations do not support Neighbor Discovery yet. See also section 8.

2 Introduction

This Plugtests event aimed to test the interoperability of 6LoWPAN Host, 6LR and 6LBR implementations.

The implementations were using IEEE 802.15.4-2006 2.4 GHz PHY/MAC. It was proposed also to run test over IEEE 802.15.4g 868 MHz but no company attended the event bringing such implementations.

A Plugtests guide was produced containing 29 interoperability tests on 6LoWPAN covering Header Compression (RFC 6282), Neighbor Discovery (RFC 6775) and 6LoWPAN Frame Format.

ETSI provided the interoperability tool suite of wiki, Test scheduling, online test reporting tool. Also some sniffers and simple spectrum analyzers were available to help participants to debug any issues.

During the event, Technical expertise has been provided by Plugtests team but also by the FP7 Probe-IT (represented by IRISA/Université de Rennes 1 and BUPT), IPv6 Forum (represented by University of New Hampshire), and IPSO Alliance.

For the 2 days event, test sessions for IOP assessment were conducted. At the end of each day a wrap-up meeting was held to discuss main interoperability points of the day.

3 Base Specifications

The following documents were used as basis for the tests:

[1] RFC 4944: Transmission of IPv6 Packets over IEEE 802.15.4 Networks

[2] RFC 6282: Compression Format for IPv6 Datagrams over IEEE 802.15.4-Based Networks

[3] RFC 6775: Neighbor Discovery Optimization for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs)

[4] Constrained Application Protocol (CoAP); draft-ietf-core-coap-18
(as a supporting specification; interoperability with this specification was not specifically a target of the testing)

4 Abbreviations

6LoWPAN	IPv6 over Low power Wireless Personal Area Networks
CoAP	Constrained Application Protocol
NO	Test is recorded as NOT successfully passed.
NA	Test is not applicable.
OK	Test is recorded as successfully passed.
OT	Test is recorded as not being executed due to lack of time.
Test Session	A paring of vendors that test together during a given time slot.
TSR	Test Session Report. Report created during a test session.

5 Participants

The companies which attended the Plugtests are listed in the table below.

Table 1: List of implementations that participated in the tests

#	Company
1	CNRS-LIG
2	Ghent University - iMinds
3	HAW HAMBURG
4	RIOT - INRIA
5	Telecom Bretagne
6	University of Bremen
7	Purdue University
8	Virtenio GmbH
9	Mimos

Table 2: List of Plugtests team

#	Company	Role
1	**ETSI**	Organization of Plugtests, Test Network, Test Descriptions
2	**IRISA/Université de Rennes 1**	Technical expertise
3	**BUPT**	Technical expertise
4	**UNH**	Technical expertise
5	**IPSO Alliance**	Technical expertise
6	**Easy Global Market**	Technical expertise

6 Technical and Project Management

All the information presented in this chapter is an extract of the ETSI event wiki https://services.plugtests.net/wiki/6LoWPAN/index.php/Main_Page (Access for registered people only).

6.1 Test Plan

The test plan containing 29 interoperability tests was developed by ETSI CTI together with Probe-IT, IPSO Alliance and IPv6 Forum. Two preparation conferences calls took place with the participants prior to the event, where it was proposed to companies to review the test scenarios. Participants had also the opportunity to propose additional tests.

The tests were grouped in 4 categories:

FORMAT	Frame format
ND	Neighbor Discovery (RFC 6775)
HC	Header Compression (RFC 6282)
ND-HC	Combined ND-HC

Id	Test Id	Test Summary	Test Group
1	TD_6LoWPAN_FORMAT_01	Check that EUTs correctly handle uncompressed 6LoWPAN packets (EUI-64 link-local)	FORMAT
2	TD_6LoWPAN_FORMAT_02	Check that EUTs correctly handle uncompressed 6LoWPAN packets (16-bit link-local)	FORMAT
3	TD_6LoWPAN_FORMAT_03	Check that EUTs correctly handle uncompressed 6LoWPAN fragmented packets	FORMAT
4	TD_6LoWPAN_FORMAT_04	Check that EUTs correctly handle maximum size uncompressed 6LoWPAN fragmented packets	FORMAT
5	TD_6LoWPAN_FORMAT_05	Check that EUTs correctly handle uncompressed 6LoWPAN multicast to all-nodes (16-bit link-local)	FORMAT
6	TD_6LoWPAN_FORMAT_06	Check that EUTs correctly handle uncompressed 6LoWPAN multicast to all-nodes (EUI-64 link-local)	FORMAT
7	TD_6LoWPAN_FORMAT_07	Check that EUTs correctly handle uncompressed 6LoWPAN packets (EUI-64 to 16-bit link-local)	FORMAT
8	TD_6LoWPAN_FORMAT_08	Check that EUTs correctly handle uncompressed 6LoWPAN packets (16-bit to EUI-64 link-local)	FORMAT
9	TD_6LoWPAN_HC_01	Check that EUTs correctly handle compressed 6LoWPAN packets (EUI-64 link-local, hop limit=64)	HEADER COMPRESSION
10	TD_6LoWPAN_HC_02	Check that EUTs correctly handle compressed 6LoWPAN packets (16-bit link-local, hop limit=64)	HEADER COMPRESSION
11	TD_6LoWPAN_HC_03	Check that EUTs correctly handle compressed 6LoWPAN packets (EUI-64 link-local, hop limit=63)	HEADER COMPRESSION
12	TD_6LoWPAN_HC_04	Check that EUTs correctly handle compressed 6LoWPAN packets (16-bit link-local, hop limit=63)	HEADER COMPRESSION
13	TD_6LoWPAN_HC_05	Check that EUTs correctly handle compressed UDP packets (EUI-64, server port 5683)	HEADER COMPRESSION
14	TD_6LoWPAN_HC_06	Check that EUTs correctly handle compressed UDP packets (16-bit, server port 5683)	HEADER COMPRESSION
15	TD_6LoWPAN_HC_07	Check that EUTs correctly handle compressed UDP packets (EUI-64, server port 61616)	HEADER COMPRESSION
16	TD_6LoWPAN_HC_08	Check that EUTs correctly handle compressed UDP packets (16-bit, server port 61616)	HEADER COMPRESSION
17	TD_6LoWPAN_HC_09	Check that EUTs correctly handle compressed 6LoWPAN	HEADER

		packets (EUI-64 to 16-bit link-local, hop limit=64)	COMPRESSION
18	TD_6LoWPAN_HC_10	Check that EUTs correctly handle compressed 6LoWPAN packets (16-bit to EUI-64 link-local, hop limit=64)	HEADER COMPRESSION
19	TD_6LoWPAN_ND_01	Check that a host is able to register its global IPv6 address (EUI-64)	NETWORK DISCOVERY
20	TD_6LoWPAN_ND_02	Check that a host is able to register its global IPv6 address (16-bit)	NETWORK DISCOVERY
21	TD_6LoWPAN_ND_03	Check Host NUD behavior	NETWORK DISCOVERY
22	TD_6LoWPAN_ND_04	Check 6LR NUD behavior (ICMP version)	NETWORK DISCOVERY
23	TD_6LoWPAN_ND_05	Check 6LR NUD behavior (UDP version)	NETWORK DISCOVERY
24	TD_6LoWPAN_ND_06	Check host behavior under multiple prefixes (EUI-64)	NETWORK DISCOVERY
25	TD_6LoWPAN_ND_07	Check host behavior under multiple prefixes (16-bit)	NETWORK DISCOVERY
26	TD_6LoWPAN_ND_HC_01	Check that EUTs make use of context 0 (EUI-64)	COMBINED HC-ND
27	TD_6LoWPAN_ND_HC_02	Check that EUTs make use of context 0 (16-bit)	COMBINED HC-ND
28	TD_6LoWPAN_ND_HC_03	Check that EUTs make use of context ≠ 0 (EUI-64)	COMBINED HC-ND
29	TD_6LoWPAN_ND_HC_04	Check that EUTs make use of context ≠ 0 (16-bit)	COMBINED HC-ND

6.2 Test Scheduling

During the test event the test schedule was updated according to the progress of the test sessions. This was done during the daily wrap-up meetings at the end of each day and during face-to-face meetings with the participants.

The figure below shows the final version of the test schedule.

Figure 1: Test Schedule

		Area 1	Area 2	Area 3	Area 4
Sat 27	9:00-10:30	CNRS/LIG CNRS/LIG - Host	Uni Bremen Uni Bremen - Host	Virtenio Virtenio - Host	
		iMinds iMinds - LR6	Telecom Bretagne Telecom Bretagne - LR6	RIOT RIOT - LR6	
	10:30-12:00	University of Purdue Uni Purdue - Host	Virtenio Virtenio - Host	CNRS/LIG CNRS/LIG - Host	iMinds iMinds - Host
		Uni Bremen Uni Bremen - LR6	iMinds iMinds - LR6	Telecom Bretagne Telecom Bretagne - LR6	Virtenio Virtenio - LR6
	13:00-14:30	University of Purdue Uni Purdue - Host	RIOT RIOT - Host	Uni Bremen Uni Bremen - Host	
		Telecom Bretagne Telecom Bretagne - LR6	iMinds iMinds - LR6	Virtenio Virtenio - LR6	
	14:30-16:00	iMinds iMinds - LR6	Virtenio Virtenio - Host	iMinds iMinds - Host	
		Telecom Bretagne Telecom Bretagne - Host	Uni Bremen Uni Bremen - LR6	Telecom Bretagne Telecom Bretagne - LR6	
	16:00-17:30	Uni Bremen Uni Bremen - Host	RIOT RIOT - Host	University of Purdue Uni Purdue - Host	iMinds iMinds - Host
		iMinds iMinds - LR6	Telecom Bretagne Telecom Bretagne - LR6	Virtenio Virtenio - LR6	Uni Bremen Uni Bremen - LR6
Sun 28	9:00-10:30	Virtenio Virtenio - Host	University of Purdue Uni Purdue - Host	CNRS/LIG CNRS/LIG - Host	
		Mimos Mimos - LR6	iMinds iMinds - LR6	Uni Bremen Uni Bremen - LR6	
	10:30-12:00	iMinds iMinds - Host	CNRS/LIG CNRS/LIG - Host		
		Mimos Mimos - LR6	Virtenio Virtenio - LR6		
	13:00-14:30	Virtenio Virtenio - Host	RIOT RIOT - LR6	RIOT RIOT - Host	CNRS/LIG CNRS/LIG - Host
		Telecom Bretagne Telecom Bretagne - LR6	Telecom Bretagne Telecom Bretagne - Host	Virtenio Virtenio - LR6	Mimos Mimos - LR6
	14:30-16:00	Uni Bremen Uni Bremen - Host	CNRS/LIG CNRS/LIG - Host	RIOT RIOT - Host	Telecom Bretagne Telecom Bretagne - Host
		Mimos Mimos - LR6	RIOT RIOT - LR6	Uni Bremen Uni Bremen - LR6	Virtenio Virtenio - LR6
	16:00-17:30	University of Purdue Uni Purdue - Host	Telecom Bretagne Telecom Bretagne - Host	RIOT RIOT - LR6	
		Mimos Mimos - LR6	Uni Bremen Uni Bremen - LR6	iMinds iMinds - Host	
	17:30-19:00	Telecom Bretagne Telecom Bretagne - Host	Uni Bremen Uni Bremen - Host		
		Mimos Mimos - LR6	RIOT RIOT - LR6		

6.3 Interoperability Test Procedure

Each test was executed in the same manner as listed below:

1) Connect host and router over test network

2) Check connectivity between devices

3) Perform tests according to Plugtests Guide

   a. Check if test runs to completion

   b. Check results from an interoperability point of view:
      Is the intended result visible at the application layer?

4) Result determination and reporting

   a. Result OK: run next test

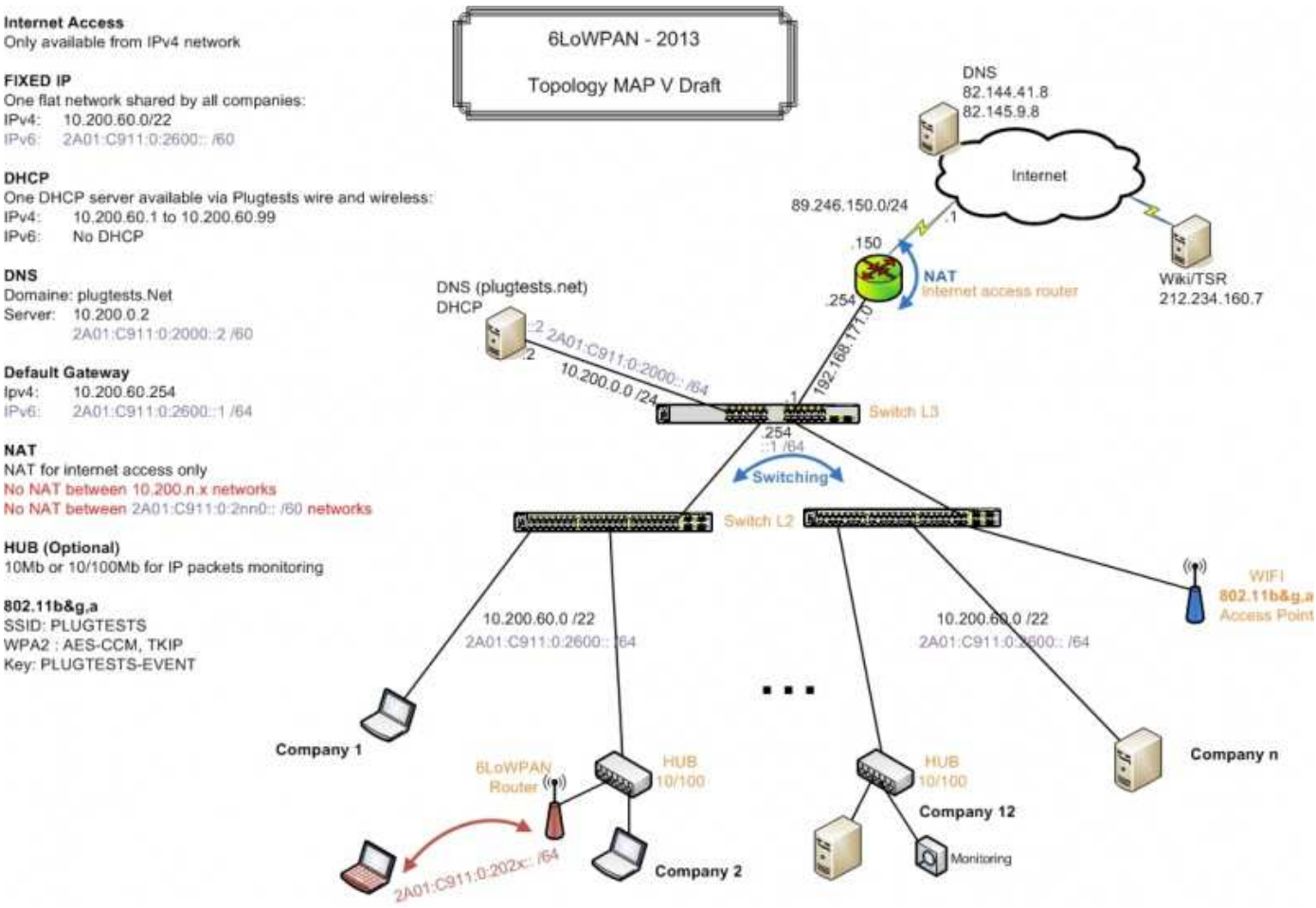
   b. Result not OK: check monitor tools to identify source of error

   c. Report results in ETSI Test Reporting Tool

6.4 Test Infrastructure

The test infrastructure provided for the Plugtests is shown below.

Figure 2: Test Network



6.5 Tooling

6.5.1 ETSI Test Reporting Tool

The purpose of the ETSI Test Reporting Tool is to provide a means to report the test sessions. It provides statistical overviews of the test results. The graphical information in the latter section on results was created with the ETSI Test Reporting Tool. It also provides a means to create a test schedule (see section 6.2).

6.5.2 2.4 GHz 802.15.4 sniffers

We had available three USB-based 2.4 GHz 802.15.4 sniffer boards (Econotag), i.e. one per pairing. To use one of the sniffer boards, participants installed necessary software (Wireshark 1.10.0, Python 2.x, pyserial, and the rftestrx2pcap.py script) on one of their own laptops as per the Econotag documentation.

Python script at: http://www.tzi.org/~cabo/rftestrx2pcap.py

Run as:

python rftestrx2pcap.py /dev/cu.usbserial-000013FAB 26 | wireshark -k -i -

For sniffing channel 26 etc. (/dev/cu.usbserial-000013FAB may differ on your system — use the higher numbered one of the two USB serials created.)

7 Achieved Results

The achieved results show that all implementations have been compatible on a basic level, i.e. sent data could be decoded and interpreted properly by receivers and a vast majority of equipment performed well.

7.1 Overall Results

Due to NDA constraints, it is not possible to provide detailed results.

The figure 4 below shows the overall result of interoperability tests.

The execution rate of 21.8% is low result, especially as considering the small number of tests proposed (29 tests) in such short event. Going deeper in the analysis, it appears that this low rate is fully due to the fact that the tests about ND and combined HC-ND have not been completed by any organization. It was an important part of the tests proposed.

Among the tests that have been performed, 91.4% of the test verdicts were OK which shows an overall high level of maturity of the feature implemented, especially about Header Compression (95.7% OK).

Overall Results					
Interoperability		Not Executed		Totals	
OK	NO	NA	OT	Run	Results
139 (91.4%)	13 (8.6%)	463 (66.5%)	81 (11.6%)	152 (21.8%)	696

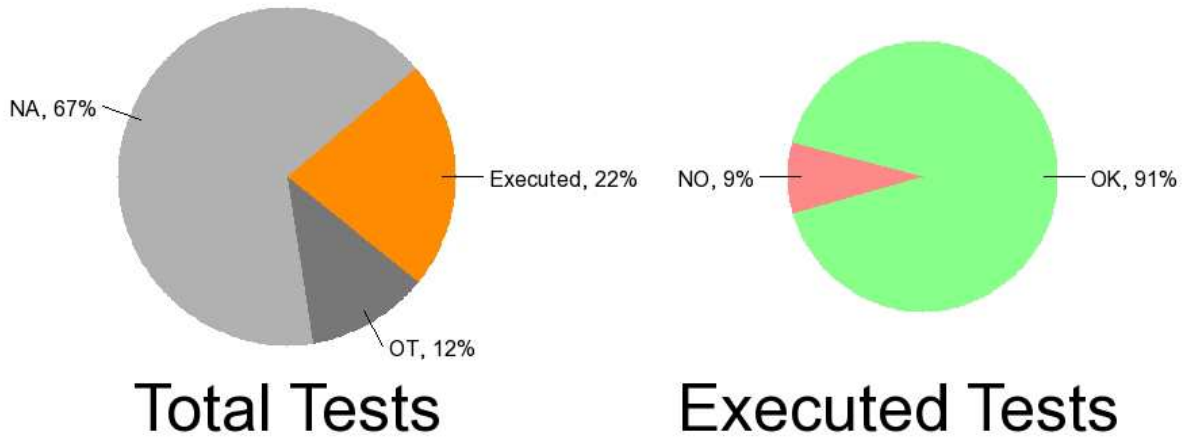


Figure 4: Overall Results

Results per Test group:

	Interoperability		Not Executed		Totals	
Group	OK	NO	NA	OT	Run	Results
COMBINED HC-ND	0 (0.0%)	0 (0.0%)	**82 (85.4%)**	14 (14.6%)	0 (0.0%)	96
FORMAT	**73 (88.0%)**	10 (12.0%)	98 (51.0%)	11 (5.7%)	83 (43.2%)	192
HEADER COMPRESSION	**66 (95.7%)**	3 (4.3%)	**145 (60.4%)**	26 (10.8%)	69 (28.8%)	240
NEIGHBOR DISCOVERY	0 (0.0%)	0 (0.0%)	**138 (82.1%)**	30 (17.9%)	0 (0.0%)	168

8 Technical Wrap-Up

8.1 IOP Issues

One surprising issue that influenced the course of the Plugtests somewhat was that one implementation could only be reliably tuned to a subset of the 16 channels standardized in IEEE 802.15.4 for 2.4 GHz operation. On site, this could be worked around by assigning one of the channels, 26, to all tests specifically with that implementation. Future test plans should add tests with respect to channel agility.

Many of the tests that failed initially (and often were quickly repaired by the present engineers) were testing the uncompressed mode. See clause 8.3 “base specification issues” below.

Some implementations had surprising byte swap issues in uncompressed mode (which could be corrected quickly). These do not always come up immediately in interoperability tests as many implementations do not actually inspect fields such as the IP version number in uncompressed mode, but some do.

Compliance with RFC 6775 (6LoWPAN-ND) is still very low in the research stacks that some participants were either using directly or as a source of component code. We saw a lot of multicast neighbour solicitations — when these weren’t answered (which is the correct behaviour with RFC 6775), sometimes the test didn’t proceed. It shows that specific effort is required to update research stacks to the current standard. The Plugtests team provided this feedback to IETF. Consequently, some further discussions were held during the IETF meeting following the Plugtests in order to expedite progress on this. This problem explains the small number of 6LoWPAN-ND tests that were actually completed.

8.2 Test Spec Issues

Feedback received during the Plugtests is listed here below and needs to be implemented for a future event.

The test specification assumes that implementations can combine 16- und 64-bit addresses in one interchange. Not all implementations could be configured to do that. This should be clearly marked as an optional test in the next Plugtest.

A number of the ND and combined HC/ND tests could not be configured by any pair of the participants. During preparation of the next Plugtests, preparation for these tests needs to be emphasized early in the process.

No other suggestions on the test specification were received during the Plugtests.

8.3 Base Specification Issues

6LoWPAN does not specify a specific rate in which implementations must be able to process the multiple fragments of a fragmented packet. Many senders send these tightly spaced, i.e. at the maximum rate. We found that implementations that divide the work between multiple processors (or processes) may run into buffering problems with larger fragmented packets. It is, however, difficult for a sender to choose an appropriate lower rate: there are no usable feedback signals. More data needs to be collected from other implementations that were not present in Berlin. Barring surprises from this, the base specification should probably be augmented by an implementation note that "line rate" reception of the fragments of an MTU-size packet (1280 bytes) is an expected performance property necessary for wide interoperability, and that the required buffer space for this needs to be made available in implementations that cannot consume frames at PHY rate.

As discussed above, uncompressed mode is often not well tested and is a source of interoperability problems. Since RFC 6282 is now widely implemented, it is probably desirable to deprecate RFC 4944's uncompressed mode. Discussion of such a deprecation process has started in the IETF following the Plugtests feedback; in particular, more data needs to be collected from other implementations that were not present in Berlin.

Annex A: 6LoWPAN Interoperability Test Specification

The 6LoWPAN Interoperability Test Specification, which forms parts of the present technical report, is contained in the file 6LoWPAN_TestSpecification_1.0.pdf.

History

Document history		
V0.0.1	05 Aug 2013	Initial version
V0.0.2	2 Sept 2013	Added Technical Wrap-Up clause
V1.0.0	5 Sept 2013	Final version