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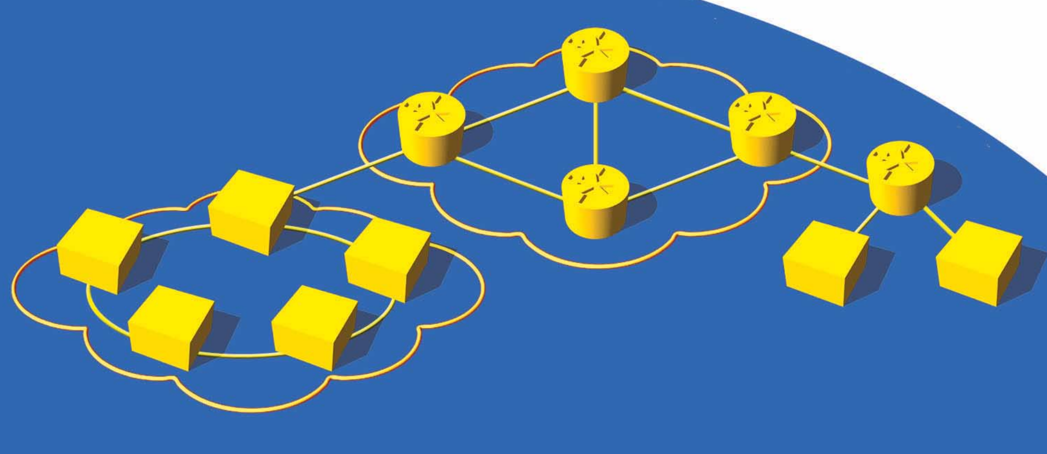
White Paper

Broadband Access Testing Methodology and Case Studies

March 2003



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Broadband Access Testing Methodology and Case Studies

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Introduction

Broadband access refers to a variety of advanced transmission methods that allow high-speed (greater than 1.5 Mbps) access to the end users. Such technologies currently include xDSL, cable modem, FTTC (Fiber-To-The-Curb), FTTH (Fiber-To-The-Home), MMDS (Multipoint Multichannel Distribution Services), LMDS (Local Multichannel Distribution Services) and satellite. To date, xDSL and cable modem have seen the widest deployment worldwide. Broadband access testing presents some unique issues and challenges for test engineers. For example, many broadband access methods have asymmetrical bandwidth and the interpretation of the performance figures differ depending on the direction of transmission (downstream or upstream). This document focuses on the test and analysis issues for both xDSL and cable modem. It includes a discussion of the industry standard test procedures as well as a presentation of some sample test cases.

xDSL versus Cable Modem Technology

xDSL refers to a family of related technologies that allows high-speed transmission over telephone wires. *Table 1* describes the different variations of xDSL.

Table 1. Variations of xDSL

Technology	Characteristics
HDSL	• Provides repeaterless T1/E1 service • Runs over 2 twisted pairs
SDSL	• Provides fractional T1/E1 service over a single pair • Superseded by HDSL2
HDSL2	• Provides full T1/E1 service over a single pair
IDSL	• ISDN rate (128 Kbps)
VDSL	• Very high-speed access over short distances
ADSL	• Rate adaptive – speed changes based on line conditions • Requires either a POTS splitter or in-line filter
ADSL Lite	• Lower speed than full-rate ADSL (1.5 Mbps downstream; 512 Kbps upstream) • Splitterless ADSL

Both ADSL and cable modem technologies are being extensively deployed to provide high-speed Internet access. *Figure 1* shows the configuration for ADSL. *Figure 2 on page 4* shows the configuration for a cable modem.

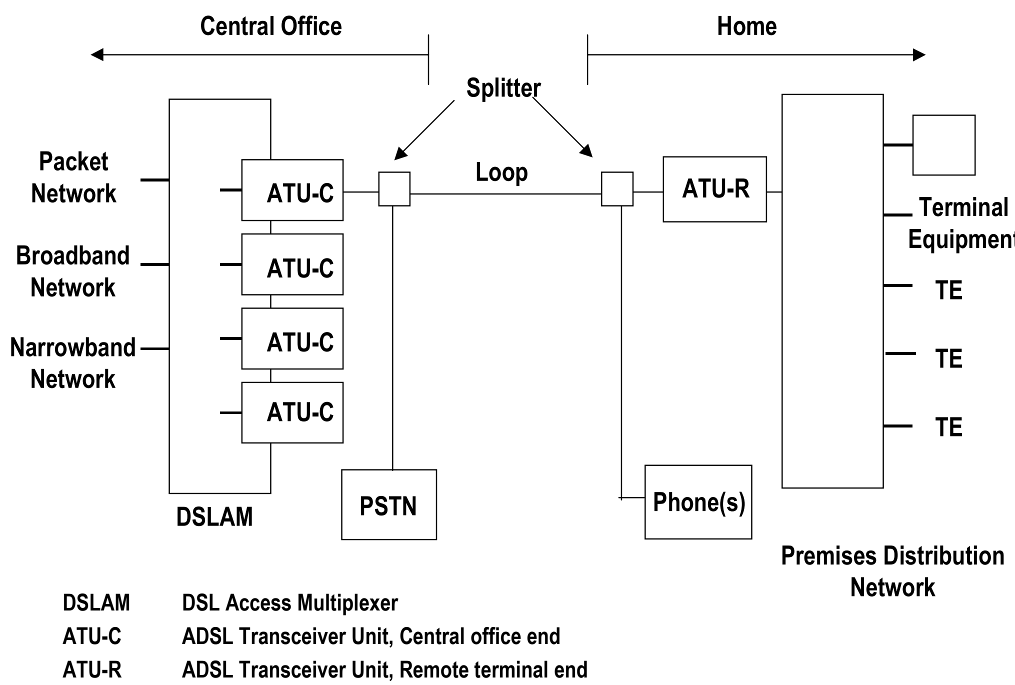
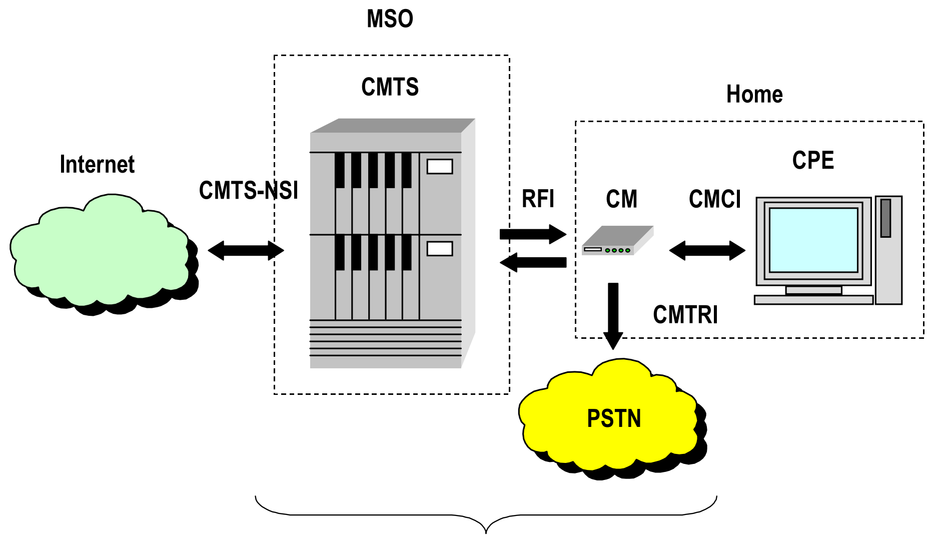


Figure 1. ADSL Reference Configuration



CM	Cable Modem
CMCI	Cable Modem-CPE Interface
CMTRI	Cable Modem Telco Return Interface
CMTS	Cable Modem Termination System
CMTS-NSI	CMTS Network Side Interface
CPE	Customer Premise Equipment
MSO	Multi-Service Office
RFI	Radio Frequency Interface

Figure 2. Cable Modem Configuration

Table 2 compares ADSL versus cable modem technology.

Table 2. ADSL versus Cable Modem

	ADSL	Cable Modem
Standardizing Organization	ANSI, ETSI, ITU-T	CableLabs
Main Standards	ANSI T1.413i2, ITU-T G.992.1 (G.dmt), ITU-T G.992.2 (G.Lite)	DOCSIS 1.0 and DOCSIS 1.1
Speeds	Downstream: 6.144 Mbps[a] Upstream: 640 kbps	Downstream: 41 Mbps[b] Upstream: 10 Mbps
Bandwidth Allocation	Dedicated	Shared
Speed Factors	Speed decreases with increased distance from CO Speed also decreases with increased interference (crosstalk)	Throughput decreases when there are more active subscribers

Table 2. ADSL versus Cable Modem (continued)

	ADSL	Cable Modem
Distance	Around 15kft	Up to 100 miles
Modulation	DMT Each subcarrier uses QAM and Trellis coding	Downstream: 256-QAM or 64-QAM Upstream: QPSK or 16-QAM
Frequency Spectrum	30 kHz to 1.1 MHz	5 MHz to 1 GHz
FEC	Yes	Optional
Initialization	ITU-T G.994.1 (G.hs): Speed and power negotiation	Ranging: Registration and power negotiation
Encapsulation	STM/ATM/ADSL superframe	DOCSIS MAC/MPEG/PMD
Security	Not defined	BPI+
QoS	CBR, rt-VBR, nrt-VBR, ABR, UBR[c]	UGS, rtPS, nrtPS, UGS/AD, BE[d]

a These are the maximum speeds as specified in the standards. In practice, most commercial products can exceed these speeds when the line conditions are good.
b The speed varies depending on the modulation method and the channel width. For example, in the downstream direction, the speed is 41 Mbps if 256-QAM is used and 31 Mbps if 64-QAM is used based on a 6 MHz channel. In Europe, the channel width is 8 MHz and the speeds are 51 Mbps and 41 Mbps depending on the modulation.
c ATM mode transport is assumed.
d Available in DOCSIS 1.1 only.

Industry Standard Test Methods

What to Test

In general, testing of network products falls into the following categories:

Conformance Testing

These tests are designed to ensure that a particular implementation conforms to a certain set of specifications. For example, if a cable modem was designed based on DOCSIS 1.1 (see *“DOCSIS 1.1 and QoS” on page 19*), then the object of conformance testing is to verify that it complies with the specification. To test for conformance, test cases have to be developed and run on an implementation. Each test case will verify a particular aspect of the specification.

Interoperability Testing

These tests are designed to ensure that implementations from different vendors will work together. For example, does the DSL modem from vendor A work with the DSLAM from vendor B, or does the cable modem from vendor A work with the CMTS from vendor B? Here the tests are designed to verify initialization, negotiation, communications and error recovery between the implementations.

Performance Testing

These tests are designed to measure the performance of an implementation under a variety of operating conditions. These can include normal, overload, and degraded conditions.

In addition, there are some additional testing issues that have to be considered in broadband access.

Direction of Transmission

Many broadband access methods have asymmetrical bandwidth (ADSL and cable modem for example). Performance depends on the direction of transmission. Downstream refers to traffic from the DSLAM or CMTS towards the CPE whereas upstream refers to traffic from the CPE towards the DSLAM or CMTS. Tests typically have to be run twice – once to determine the downstream performance and a second time to determine the upstream performance.[1]

Long Term Stability

One of the advantages of using broadband Internet access is that it is always "on." As such, we must test the components for long-term stability. For example, if the ADSL modem is left on for a long period of time, will the performance degrade?

Impaired versus Unimpaired Testing

Both DSL and cable modem transmission can be affected by line conditions. These factors include line attenuation, signal-to-noise or carrier-to-noise ratio as well as crosstalk from adjacent transmitters. Thus the testbed must be able to simulate a variety of line conditions. For example, in the case of ADSL, one of the common transceiver tests involves determining the relationship between the line speed and the distance between the ATU-R and the ATU-C.

1. In some cases, it is also interesting to have downstream and upstream traffic simultaneously. If the CPE LAN is half-duplex, this will create collisions under a heavy load.

Test Procedures for Digital Subscriber Line Transceivers

The test procedures are defined in ITU-T Draft G.996.1 (G.Test). The document defines methods for testing DSL transceivers in the presence of impairments. It defines the electrical characteristics of a set of test loops that are common in Europe and North America. It also defines the Power Spectral Density (PSD) of common disturbers that can create crosstalk for the DSL transceivers.

ADSL Testing

This is a document written by the DSL Forum as Technical Report TR-023. It provides an overview of the testing of ADSL equipment. Specifically, it defines three areas of tests: conformance, static interoperability and dynamic interoperability.[2] More detailed test documents have also been written. For example, TR-026 defines the Implementation Conformance Statement (ICS) for ANSI T1.413i2 and TR-029 defines the dynamic interoperability tests.

CableLabs Acceptance Tests

CableLabs has a program for certifying cable modems and cable modem termination systems for interoperability. The tests that are run are defined in the Interoperability Test Plan (TP-I07-980807). The document describes a series of tests that will verify the interoperability between CMs and CMTSs as well as measure their performance.

IETF Benchmarking Methodology

The IETF Benchmarking Methodology Working Group (BMWG) has published a number of RFCs on benchmarking terminology and methodology for different classes of internet working devices. While none of the RFCs are specifically addressed to DSL or cable modem devices, RFCs 1242 and 2544 have general applicability to all network interconnect devices. In particular, they define four basic metrics – throughput, latency, frame loss and back-to-back – which are commonly used to describe the performance of network devices.

2. Dynamic interoperability is more commonly referred to as performance testing.

Case Studies

This section describes a series of sample test cases and the results that have been obtained. While these tests are not exhaustive, they have been selected to highlight specific issues that may arise in broadband access testing.

Throughput Testing

This is one of the most basic system tests. The objective is to measure the performance of the system. In RFC 1242, throughput is defined as the highest input traffic rate at which there is no frame loss. *Figure 3* shows the test configuration. To determine the downstream throughput, the SmartBits (running SmartxDSL or SmartCableModem Test) generates traffic from the trunk side. The DSLAM (or CMTS) and the DSL modem (or cable modem) will forward the traffic to the access side. The SmartBits will then receive and measure traffic from the access side. By stepping through different load levels, the throughput of the system can be determined. The process is reversed when the upstream throughput is to be determined. Traffic is generated from the access side and then received and measured from the trunk side.

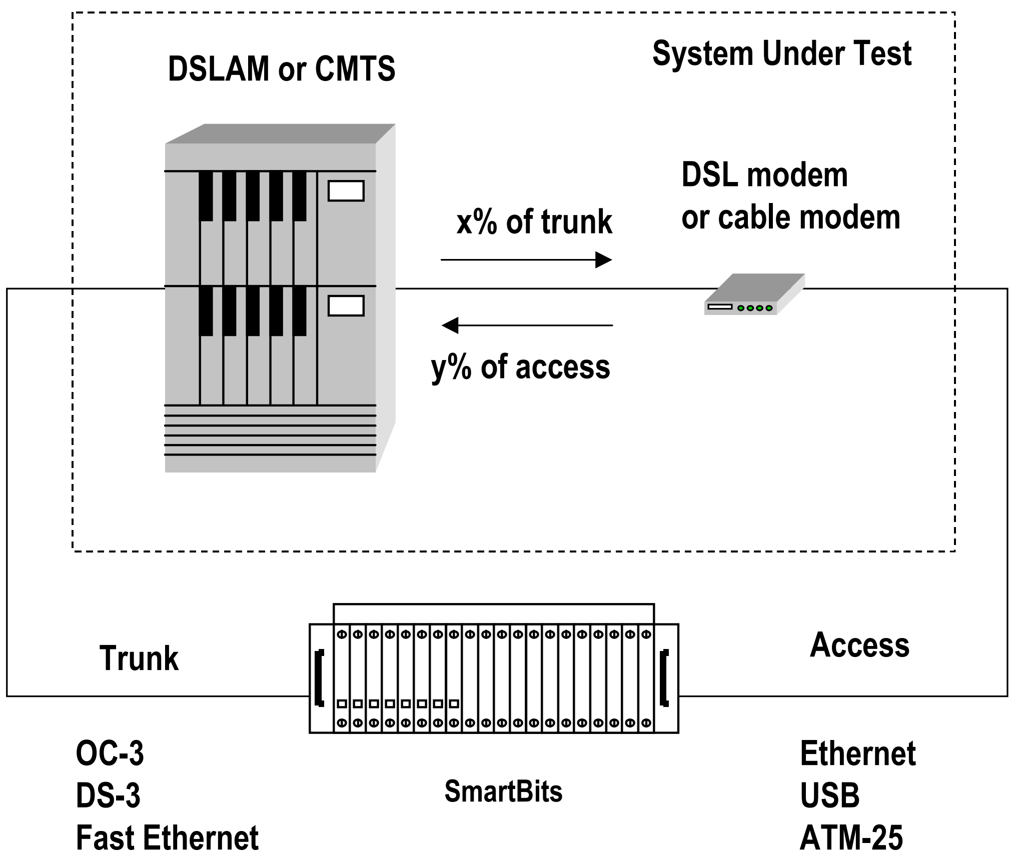


Figure 3. Throughput Test Configuration

Figure 4 shows the results of an ADSL downstream throughput test. The input load (as a percentage of the maximum trunk load) was gradually increased from 1% to 10% in 1% increments. Up to 4% load, there was no frame loss. At 5% load, 8400 frames were transmitted but only 7708 frames were received. This represented a loss of 692 frames or 8.24%. Thus the downstream throughput is around 4.5%.

SmartxDSL Test Type	**Frame Loss**							
Traffic Direction :	DownStream							
Time Started	25/01/00 14:34							
Test Duration (s)	100							
Min, Max, Step Trunk Load	1, 10, 1							
Min, Max, Step Access Load	1, 5, 1							
Trunk Port(s)	(1, 1, 1)							
Access Port(s)	(1, 5, 1)							
Connection Name	Actual Load (%)	Src Address	Dst Address	Tx Frames	Rx Frames	Lost Frames	Loss (%)	Goodput (%)
(1, 1, 1)-(1, 5, 1) s1(dn)	1	192.168.132.2	192.168.3.2	1680	1680	0	0	100
(1, 1, 1)-(1, 5, 1) s1(dn)	2	192.168.132.2	192.168.3.2	3360	3360	0	0	100
(1, 1, 1)-(1, 5, 1) s1(dn)	3	192.168.132.2	192.168.3.2	5040	5040	0	0	100
(1, 1, 1)-(1, 5, 1) s1(dn)	4	192.168.132.2	192.168.3.2	6720	6720	0	0	100
(1, 1, 1)-(1, 5, 1) s1(dn)	5	192.168.132.2	192.168.3.2	8400	7708	692	8.238095284	91.76190186
(1, 1, 1)-(1, 5, 1) s1(dn)	6	192.168.132.2	192.168.3.2	10090	6398	3692	36.59068298	63.40931702
(1, 1, 1)-(1, 5, 1) s1(dn)	7	192.168.132.2	192.168.3.2	11770	4207	7563	64.25658417	35.74341583
(1, 1, 1)-(1, 5, 1) s1(dn)	8	192.168.132.2	192.168.3.2	13450	3843	9607	71.42750549	28.57249451
(1, 1, 1)-(1, 5, 1) s1(dn)	9	192.168.132.2	192.168.3.2	15130	3590	11540	76.27230835	23.72769165
(1, 1, 1)-(1, 5, 1) s1(dn)	10	192.168.132.2	192.168.3.2	16810	25	16785	99.85128021	0.148719788

Downstream throughput between 4% and 5%

Figure 4. Sample ADSL Throughput Test Results

To evaluate the performance of the system, the relevant question is: How does the measured throughput compare with the theoretic maximum? The answer is that it depends on the negotiated speed, the frame size, and the frame encapsulation method. As an example, assume that we are trying to measure and evaluate the throughput of ADSL in the following configuration:

Trunk speed: ATM on OC-3

Access speed: 10 Mbps Ethernet

Trained downstream speed: 6080 kbps

Trained upstream speed: 832 kbps

Frame size: 64 bytes

First we must determine the maximum frame rate on the trunk side. At OC-3 rate, the maximum cell rate is about 353,207 cells per second.[3] Since each 64-byte frame must be segmented into two cells,[4] the maximum frame rate is 176,603 fps.

3. This takes into account the SONET overhead.
4. To figure out how many cells are required, the overhead bytes must be taken into account. Assuming the ADSL modem is running in bridged Ethernet mode, the RFC 1483 header will add 10 bytes. Usually the Ethernet FCS is stripped off and this saves 4 bytes from the original frame. Then the AAL5 trailer will add 8 bytes. The AAL5 PDU must then be segmented into cells with each cell holding 48 bytes of payload. Thus a 64-byte Ethernet frame becomes a 78-byte (64+10-4+8) AAL5 PDU. This requires 2 ATM cells.

On the ADSL link, the downstream speed is 6080 kbps. The maximum cell rate is about 14,339 cells per second. At 2 cells per frame, the maximum frame rate is 7170 fps. Therefore, the highest possible downstream throughput is 7170/176603 or 4.06%. When the actual test is run, if the system only yields a downstream throughput of, say 3.5%, then we can conclude that the system is not able to handle the maximum load.

Similarly, in the upstream direction, the maximum frame rate on the access side is 14,880 fps[5] based on 64-byte frames. On the ADSL link, the maximum upstream cell rate is about 1962 cells per second. This translates into a frame rate of 981 fps. Thus the highest possible upstream throughput is 981/14880 or 6.6%.

The theoretical figures will change if the frame size is different. For example, if the frame size is 1518 bytes instead of 64 bytes, each frame will have to be segmented into 32 ATM cells. Repeating the same calculations, the maximum throughput will be 4.06% downstream and 7.54% upstream.[6]

Throughput and Frame Loss

When determining throughput, it is often revealing to examine the frame loss behavior at the same time. It can help us understand the constraints within the system. *Figure 5* shows the setup of a comparative performance test of modems from three different vendors. In the test, only the downstream throughput was measured. *Figure 6 on page 11* shows the results of the throughput using both 64-byte and 1518-byte frames.

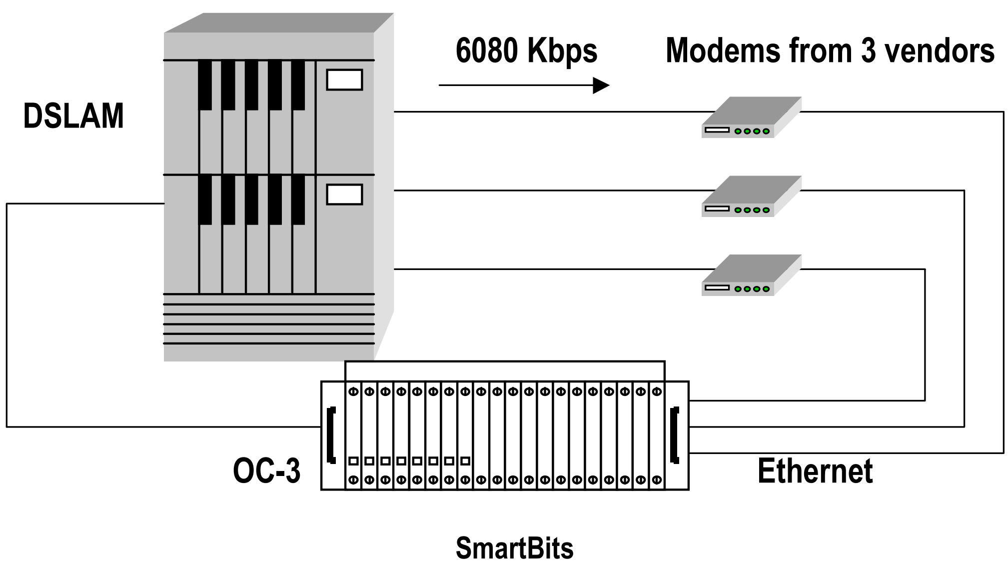


Figure 5. Comparative Performance Test

5. This takes into account the 8 byte preamble that precedes every frame and a minimum inter-frame gap of 9.6 microseconds.
6. The downstream figure did not change because the ATM overhead on the OC-3 and ADSL links is identical.

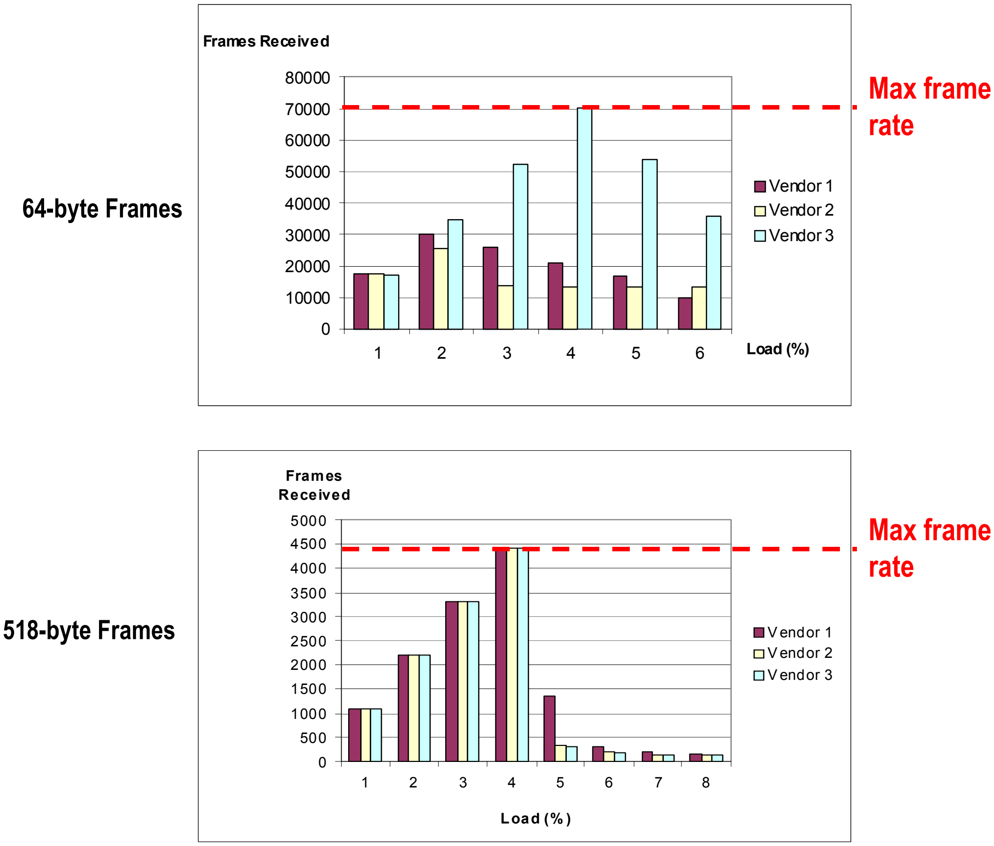


Figure 6. Comparative Performance Test Results

In *“Throughput Testing” on page 8*, we determined that at a trained downstream speed of 6080 kbps, the maximum theoretical throughput is 4.06% (7170 fps for 64 byte frames and 448 fps for 1518 byte frames). Using 64-byte frames, we can see that only vendor 3 was able to attain the maximum frame rate. The other two vendors reached their maximum performance at around 2% load. However, using 1518-byte frames, all three vendors were able to achieve the maximum frame rate. The explanation for the observed behavior is that given the same load, the frame rate is much higher for 64-byte frames compared with 1518-byte frames. For example, at the theoretical maximum of 4.06%, the frame rate of the short frames (7170 fps) is about 16 times that of the long frames (448 fps). As a result, vendors 1 and 2 could not keep up with the high frame rate and started dropping frames at around 2%. A more powerful processor would be required if the vendor wishes to improve performance.

Another observation from the test was that all modems started discarding frames once the input load exceeded the output load. This was the case for all three vendors. Furthermore, the drop off was much more severe for 1518-byte frames. In this case, when the input load was at 6%, practically all frames were dropped by all vendors. The explanation for this was that frames had to be segmented into ATM cells before they could be transmitted. Once the system became congested, cells had to be dropped. However, if one cell within the frame was dropped, the entire frame could not be reassembled. Since a 1518-byte frame had to be segmented into 32 cells, the probability that one of the cells was dropped was very high. In fact, when the input load was at 6%, the probability that all 32 cells could get through was very low.[7]

The observed behavior was clearly unacceptable. What is required for stable network operation is that the output should stay constant even under overload conditions. This can be achieved by turning on the Early Packet Discard (EPD) feature in the DSLAM. With EPD, if a cell has to be discarded, all the cells associated with the same frame will be discarded at the same time. This ensures that cells that cannot be reassembled back into a frame will not be transmitted at all. *Figure 7* shows the result of the same test with EPD turned on in the DSLAM. In this case, the output stabilized after the maximum throughput was reached.

64-byte Frames

1518-byte Frames

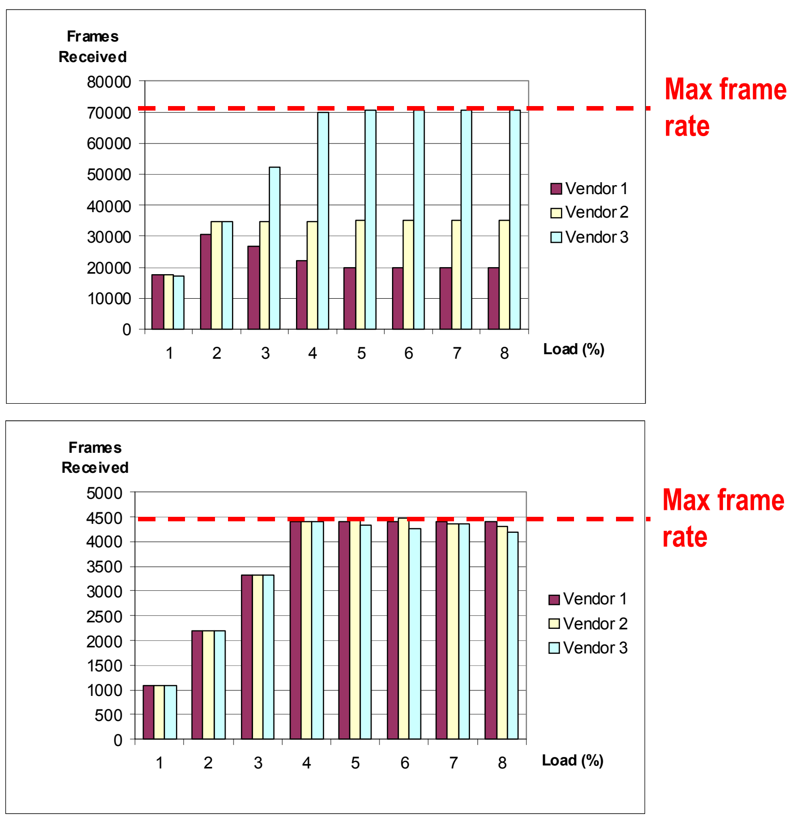


Figure 7. Comparative Performance Test with EPD Results

7. At 6% input load, the input cell rate is about 21,192 cells per second. Since the link can only pass through 14,339 cells per second, the probability of that a cell will get through is about 14339/21192 or 67.66%. The probability that all 32 cells of a frame will get through is only 67.66%^32 or 0.00037%. It was a small wonder that any frames got through at all!

Back-to-Back Test

In RFC 1242, the back-to-back test involves transmitting a burst of packets with minimum frame gap separation between frames. The purpose of the test is to determine the ability of the network interconnect device to handle wire-speed traffic for a period of time. In broadband access, there may be a speed mismatch between the trunk side, the access side, and the broadband link. In that case, the back-to-back test can be used to determine the buffering capability of the transmission system.

In the sample test, traffic was generated from a 10 Mbps Ethernet trunk port which then had to pass through a 864 kbps upstream ADSL link. The traffic consisted of bursts of frames in which each burst consisted of 400 frames transmitted back-to-back. Because of the speed mismatch, we expected that a queue would build up in the ADSL modem. If the buffer could hold fewer than 400 frames, some frame loss would occur. The point at which frame loss started to occur would give us an indication of the buffer size.

Figure 8 shows the results of the raw tags test in SmartxDSL. It recorded the latency experienced by every frame within the packet burst. Initially, the sequence numbers were consecutive but the latency increased steadily from 8.52 ms, 9.04 ms, 9.56 ms, 10.08 ms, and so on. However, after about 210 frames, the sequence numbers started to skip which indicated some frame loss. *Figure 9 on page 14* shows the results. For example, after frame number 214, the next frame was 227 which meant the loss of 12 frames in between. The frame loss continued in a similar pattern for the remainder of the burst. *Figure 10 on page 14* shows a plot of the latency and the sequence number.

Sequence #	Tx TimeStamp	Rx TimeStamp	Frame Latency(0.1µs)
0	14828	100048	85220
1	15500	105928	90428
2	16172	111812	95640
3	16844	117708	100864
4	17516	123576	106060
5	18188	129444	111256
6	18860	135328	116468
7	19532	141203	121671
8	20204	147070	126866
9	20876	152953	132077
10	21548	158824	137276
11	22220	164707	142487
12	22892	170590	147698
13	23564	176469	152905
14	24236	182360	158124
15	24908	188255	163347
16	25580	194120	168540
17	26252	199996	173744
18	26924	205876	178952
19	27596	211744	184148
20	28268	217616	189348
21	28940	223500	194560
22	29612	229368	199756

Latency buildup

Figure 8. Latency Buildup No Frame Loss

Frame Loss

Sequence #	Tx TimeStamp	Rx TimeStamp	Frame Latency(0.1µs)
210	155946	1333363	1177417
211	156618	1339223	1182605
212	157290	1345103	1187813
213	157962	1350967	1193005
214	158634	1356847	1198213
227	167370	1362699	1195329
228	168042	1368571	1200529
244	178794	1374434	1195640
245	179466	1380281	1200815
262	190890	1386180	1195290
263	191562	1392047	1200485
279	202314	1397894	1195580
280	202986	1403757	1200771
297	214410	1409616	1195206
298	215082	1415475	1200393
314	225833	1421334	1195501
315	226505	1427182	1200677
332	237929	1433042	1195113
333	238601	1438898	1200297
349	249353	1444746	1195393
350	250025	1450606	1200581
367	261449	1456462	1195013
368	262121	1462322	1200201

Figure 9. Frame Loss Started After About 210 Frames

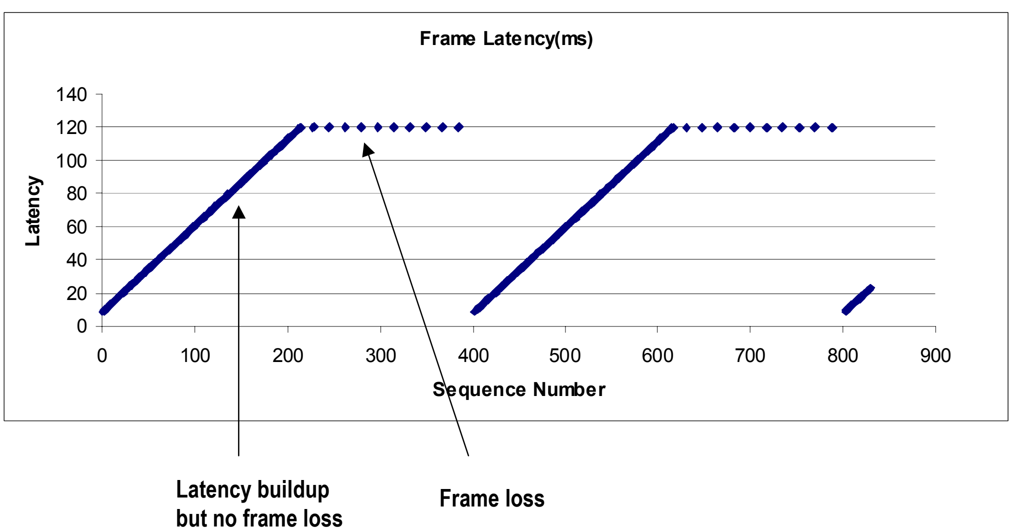


Figure 10. Back-to-Back Test

This test shows that the system under test could comfortably handle a back-to-back burst of 200 frames even with a rather large speed mismatch between the access port (10 Mbps) and the upstream channel (864 kbps). Beyond that, some frame loss will occur.[8]

Latency and Interleave

ADSL supports fast data buffer and interleaved data buffer. In the interleaved data buffer, blocks of data are interleaved (intermixed) together before they are transmitted on the link. The reason for interleaving is that it offers better protection against burst errors. However, increased error protection comes at a price of increased latency. Most ADSL equipment will allow you to adjust the interleave depth. With some equipment, the interleave depth is specified in terms of the number of interleaved bytes. In others, the depth is specified in terms of the delay.

Figure 11 shows the results of a latency test using two different interleave depths. Using a 4 ms interleave, the average latency was around 5.65 ms. After changing the interleave to 16 ms, the average latency increased to 17.67 ms – an increase of 12 ms, which was exactly the time difference between the two interleave depths. This test shows that the interleave depth has a direct latency impact on the latency.

4 ms Interleave

Connection Name	Actual Load (%)	In Sequence	Minimum (0.1 µs)	Average (0.1 µs)	Maximum (0.1 µs)
(1, 1, 1)-(1, 2, 1) s1(dn)	10	14881	56535	56560	56585
(1, 1, 1)-(1, 2, 1) s1(dn)	20	29762	56535	56556.5	56578
(1, 1, 1)-(1, 2, 1) s1(dn)	30	44643	56535	56557	56579
(1, 1, 1)-(1, 2, 1) s1(dn)	40	59524	56535	56573	56611
(1, 1, 1)-(1, 2, 1) s1(dn)	50	74405	56533	56555.5	56578
(1, 1, 1)-(1, 2, 1) s1(dn)	60	89286	56535	56560	56585
(1, 1, 1)-(1, 2, 1) s1(dn)	70	104167	56535	56558	56581
(1, 1, 1)-(1, 2, 1) s1(dn)	80	119048	56535	56558	56581

16 ms Interleave

Connection Name	Actual Load (%)	In Sequence	Minimum (0.1 µs)	Average (0.1 µs)	Maximum (0.1 µs)
(1, 1, 1)-(1, 2, 1) s1(dn)	10	14881	176753	176774	176795
(1, 1, 1)-(1, 2, 1) s1(dn)	20	29762	176752	176771.5	176791
(1, 1, 1)-(1, 2, 1) s1(dn)	30	44643	176752	176775	176798
(1, 1, 1)-(1, 2, 1) s1(dn)	40	59524	176752	176776.5	176801
(1, 1, 1)-(1, 2, 1) s1(dn)	50	74405	176750	176773	176796
(1, 1, 1)-(1, 2, 1) s1(dn)	60	89286	176750	176775.5	176801
(1, 1, 1)-(1, 2, 1) s1(dn)	70	104167	176751	176775.5	176800
(1, 1, 1)-(1, 2, 1) s1(dn)	80	119048	176752	176775	176798

Figure 11. Latency and Interleave

8. Realistically, this proves that buffers are large enough. Few applications will generate more than 200 frames in a burst without waiting for an acknowledgement from the other side.

Quality-of-Service (QoS)

Given that broadband access will carry different types of traffic, many service providers are interested in implementing QoS on their networks. The QoS mechanism differs depending on the type of broadband access. For example, for ADSL, assuming that it uses ATM transport, the QoS mechanisms will be similar to those used in ATM networks. That is, the virtual circuits can be configured to support CBR (Constant Bit Rate), rt-VBR (real-time Variable Bit Rate), nrt-VBR (non-real-time Variable Bit Rate), ABR (Available Bit Rate) and UBR (Unspecified Bit Rate). On the other hand, in cable modem, DOCSIS 1.1 defines the following service classes – UGS (Unsolicited Grant Service), UGS/AD (UGS with Activity Detection), rtPS (real-time Polling Service), nrtPS (non-real-time Polling Service) and BE (Best Effort Service). (See *"DOCSIS 1.1 and QoS" on page 19* for a description of the DOCSIS 1.1 service classes.)

When implementing QoS, it is very important to be able to test its effectiveness. In this case, effectiveness is measured by the ability of the system to provide a higher grade of service to certain types of traffic. *Figure 12* shows the configuration used for such a test. Two PVCs were provisioned to the same DSL modem. One PVC was configured for UBR service whereas the other one was configured for rt-VBR service. Since rt-VBR traffic had more stringent performance requirements, we expected it to receive a higher grade of service when competing for bandwidth with UBR traffic. Furthermore, because of the speed mismatch, we expected contention to begin when Ethernet load on the trunk side exceeded 24% per port.

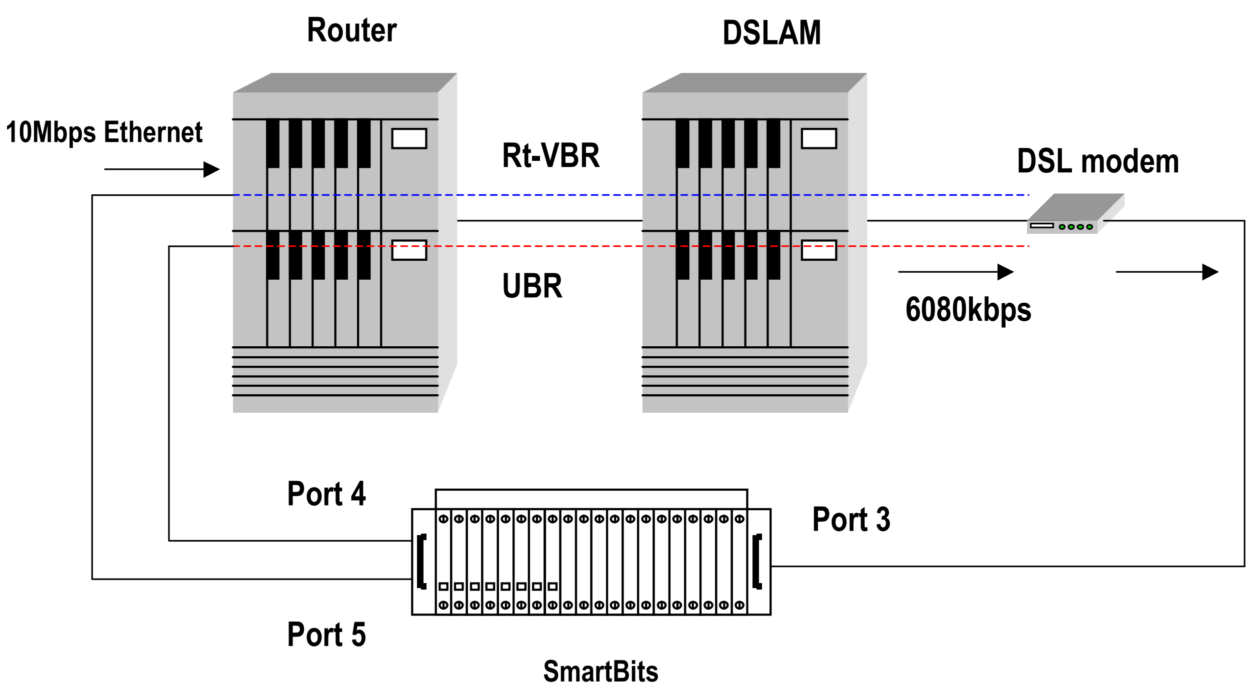
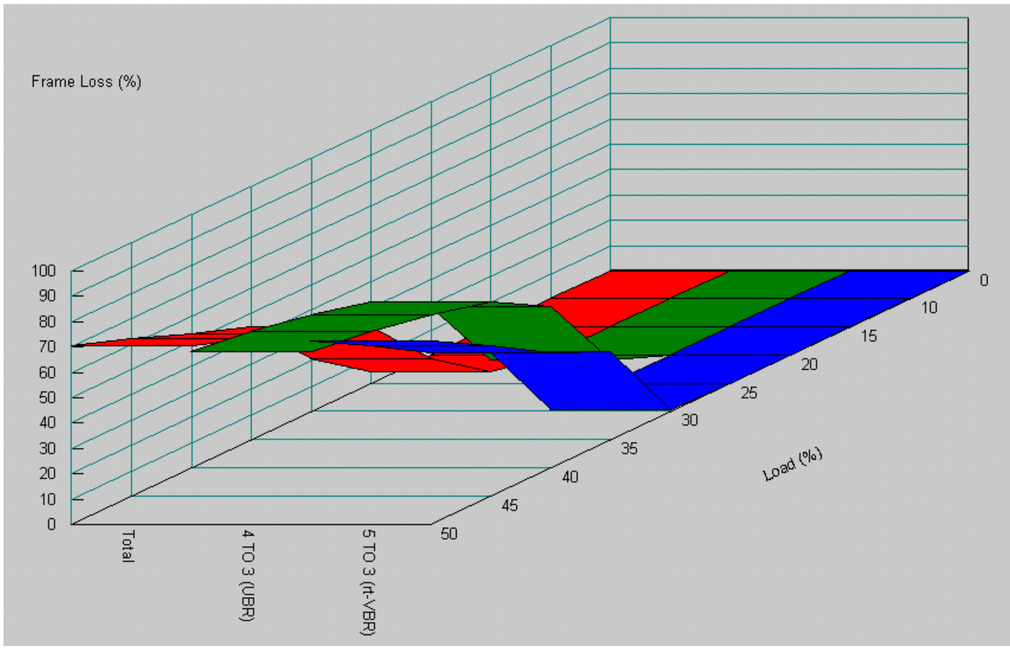


Figure 12. QoS Test

In this test, SmartFlow was used to measure performance statistics on a per-flow basis. *Figure 13 on page 18* shows the test results. When the input load exceeded 24%, frames had to be discarded. However, traffic from port 4 was discarded first. Traffic port 5 was not discarded until the input load reached 35%. This indicates that in its discard policy, the DSLAM clearly showed a preference for traffic from port 5 at the expense of traffic from port 4. The latency chart shows a similar trend. Traffic from port 5 experienced lower latency compared to traffic from port 4. This shows that ATM-style QoS can be used in ADSL to provide different service classes.



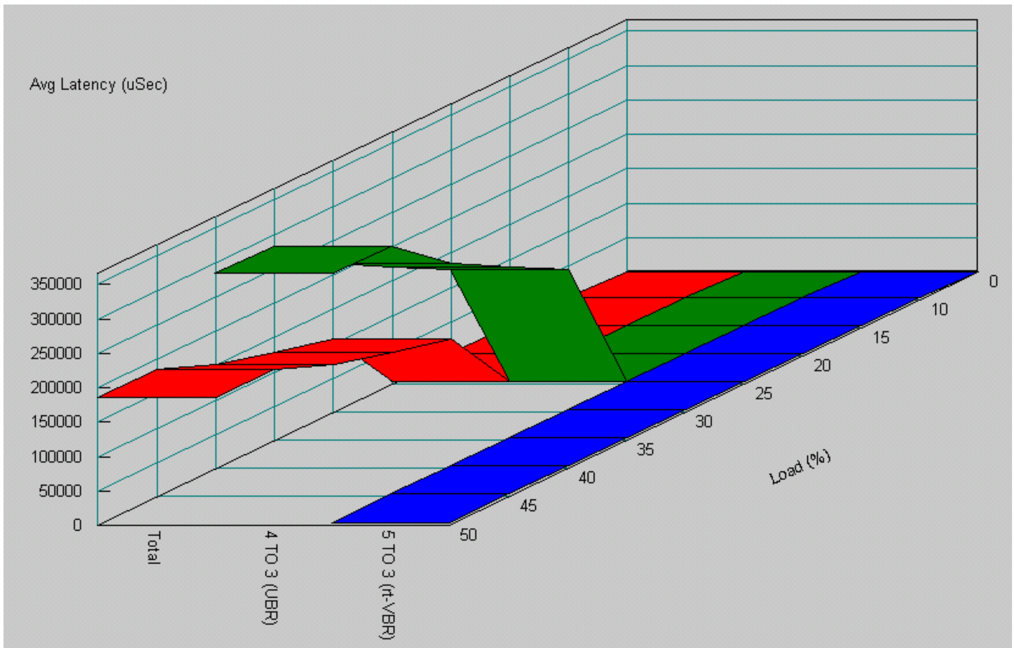


Figure 13. Frame Loss and Latency Based on QoS

The same test strategy can be used in cable modems. In CMs that support DOCSIS 1.1 QoS, packets can be classified based on a number of criteria such as IP parameters (address, TOS, TCP/UDP port number), LLC parameters (address, Ethertype, SAP) or 802.1p/802.1Q parameters. By classifying packets into different service flows, the effect can be similarly measured using SmartFlow.

DOCSIS 1.1 and QoS

DOCSIS 1.0 specified a best effort service. CMs could contend for slots and receive grants based on availability of bandwidth. Individual clients might be distinguished for favored treatment by using coarse service classes.

DOCSIS 1.1 adds facilities that can reserve resources sufficient to guarantee a minimum level of service for time critical applications, like video, or less demanding but still delay sensitive applications, like user interaction as opposed to file transfers.

DOCSIS defines specific facilities, outlined later, but leaves room for innovation on the part of vendors in coming up with alternate allocation algorithms. For example, one might implement a round robin algorithm to share bandwidth, or some weighted queuing scheme, or even a tariffed credit system where a user pays for bandwidth during periods of congestion.

The only constraint on the part of CMTS and CM vendors is that they conform to the base definitions of the mechanisms and not integrate assumptions as to policy. For example, although DOCSIS 1.1 provides for a class of service whereby a CM regularly is assigned some upstream bandwidth, a CM must not assume that a minimum amount of upstream bandwidth will always be available to it since congestion may occasionally violate the assumption; i.e. it may ask for guaranteed bandwidth and be refused.

Service Flows

A Service Flow is a unidirectional flow of packets that provides a particular QoS. The CM and CMTS provide this QoS by shaping, policing, and prioritizing traffic according to the QoS parameter set that was defined for that flow. A flow is referenced via a Flow Identifier. Separate flows control upstream and downstream traffic even if the flows apply to a single application session.

Service Flows only affect the traffic on the cable network. Beyond that, whether on the other side of the CMTS or the CM, vendors may supplement DOCSIS QoS by implementing whatever QoS mapping, queuing, or admission control strategies they wish.

Packet classifiers analyze packets and assign each to one particular service flow. The decision is based on the usual criteria for QoS implementation in routers or switches, including 802.3 source or destination MAC address, Ethertype, 802.1 priority, 802.1 VLAN identifier, IP source and destination address, transport and higher level protocols, transport protocol source or destination port, and higher level information as supported by the device.

QoS parameters for a flow include commitments for throughput, latency, and jitter.

An initial set of service flows for a CM is defined in its configuration file downloaded from CMTS at initialization time. Flows can also be dynamically created. All QoS flow definitions or modifications require authorization by the CMTS, in part to ensure that they can be met, and in part to prevent abuse.

Scheduling Services

Assigning packets to service flows only defines the desired QoS. Admission controls and queuing achieve part of the implementation of QoS. Some of the implementation requires very explicit recognition of cable's unique upstream transmission characteristics. Recall that in the normal case, a CM may have to negotiate for upstream bandwidth over a number of transactions. Five scheduling services are required to ensure that QoS parameters for each upstream flow from each CM can be respected by anticipating bandwidth requirements. There is no similar problem for downstream QoS management since the CMTS controls all aspects of downstream traffic.

Unsolicited Grant Service

To support real time requirements akin to ATM CBR, bandwidth is pre-granted to a CM in a steady stream reflected in successive bandwidth allocation maps; parameters include grant size (how much), grant interval and how many grants per interval (how often), as well as inter-grant jitter (how much leeway is there for the CMTS to lag or advance a grant).

Real Time Polling Service

To support real time requirements akin to ATM Real Time VBR. Instead of pre-granting bandwidth, a CM is polled for its requirements at relatively short intervals. The CM may request varying amounts of bandwidth depending upon its current activity.

Unsolicited Grant Service with Activity Detection

This combines elements of the previous two services to economize bandwidth when a constant bit rate application becomes idle for prolonged periods. Voice codecs that stop emitting bits during silences are the prime target.

Non-Real Time Polling Service

This service is similar to the Real Time Polling Service but polls much less frequently. It also incorporates minimum and maximum throughput thresholds to meter usage. The effect is much like ATM Non-Real Time VBR.

Best Effort Service

This service is similar to the preceding service, but with fewer polls and fewer unsolicited grants. It is typically used for lower priority traffic.

Stress Testing the DSLAM or CMTS

The objective of the test is to determine the effect of a large number of downstream devices on the DSLAM or CMTS. In the case of ADSL, the objective is to determine if the DSLAM can become the bottleneck. In the case of a cable modem, the performance factors are more subtle. The CMTS can become the bottleneck. However, the downstream and upstream bandwidth is also shared among the subscribers. More active subscribers mean that the bandwidth available to each subscriber is less. Furthermore, contention for upstream bandwidth has its own overhead. Before sending a message, the CM has to send a message to the CMTS to request for bandwidth and the CMTS has to send a message back to grant bandwidth to the CM.

In the sample test, a large number of CMs were connected to a CMTS. Six upstream channels were configured. The CMs were turned on a group at a time to gradually increase the load on the CMTS. Because of the presence of upstream contention, some frame loss can occur even at low input load. Using the strict definition of throughput in RFC 1242 was deemed to be not appropriate in this case. Instead, throughput was modified to refer to the point at which frame loss increased quickly. This turned out to be quite easy to determine when the results were plotted on a graph.

Figure 14 on page 22 shows the plot of the output versus input with 6 CMs transmitting. When the input load per port was 1.1%, the frame loss rate was 0.0204% and the aggregate output was 660,307 bits/s. When the input load was subsequently increased to 1.25%, the frame loss rate increased to 9.4% and the aggregate output only increased marginally to 679,594 bits/s. Using the more relaxed definition, the “throughput” was determined to be 660,307 bits/s.

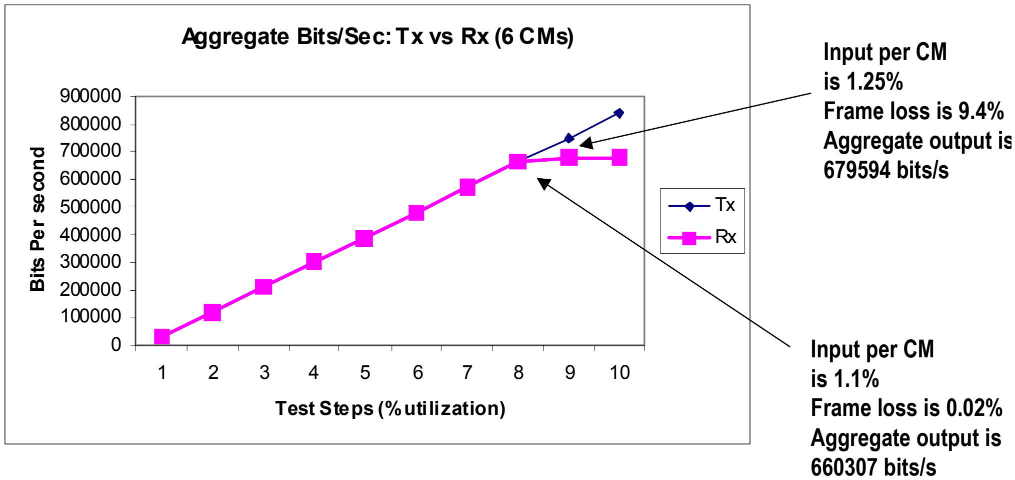


Figure 14. 6 CMs Transmitting on 6 Upstream Channels

Table 3 shows the results when more CMs were turned on.

Table 3. Increased number of CMs

Number of CMs	Input Load (%)	Frame Loss Rate (%)	Aggregate Output (kbps)
6	1.1	0.02	660
12	0.95	0.07	1140
18	0.8	0.09	1439
24	0.8	0.08	1919
30	0.8	0.08	2399
36	0.8	0.07	2879
42	0.95	0.13	3988
48	0.8	0.06	3839
54	0.8	0.08	4318
60	0.95	0.23	5692
66	0.95	0.39	6251
72	1.1	0.16	7912
78	0.95	0.07	7411

The results show that the upstream throughput was limited by the bandwidth allocation mechanism. With 6 CMs, the aggregate output was 660 kbps. When the number of CMs was doubled, the output increased to 1140 kbps (72.7% increase). Thus with more CMs, more of the upstream channels could be used and the output was higher. The output continued to increase when more CMs were added.

Line Impairment

The objective of the line impairment test was to observe the behavior of the system under more realistic or even degraded line conditions.

As mentioned previously, ITU-T G.996.1 defines a variety of test conditions for DSL transceivers. These test conditions simulate the effect of:

- Standard North American and European test loops
- Crosstalk (both NEXT and FEXT) as a result of disturbers in the same binder group or in an adjacent binder group
- Impulse noise
- POTS interference.

Table 4 shows an example of the performance of ADSL as defined in G.992.1 appendix F.

Table 4. ADSL Performance

Loop sets	ATU Category	Downstream Speed (kbps)	Upstream Speed (kbps)
T1.601 (7,13)	I	1696	160
CSA (4,6,7), Mid-CSA	I	6144	224
T1.601 (7,9,13)	II	1696	160
CSA (4,6,8), Mid-CSA	II	6144	640

The electrical characteristics of each loop set are defined in G.996.1. For example, T1.601 #7 is defined as a loop which consists of a 26 AWG twisted pair that has a span of 13.5 kft (4115 m). Similarly, other loop configurations may include the use of different wire gauges, different cable lengths, as well as different bridge tap configurations.

In addition to varying cable lengths, the standard also specifies that tests should be conducted in the presence of disturbers. *Table 5 on page 24* shows the disturbers that should be tested.

Table 5. Disturbers that Should be Tested – Category 1

Test loops	Margin (dB)	ADSL NEXT and FEXT	HDSL NEXT	DSL NEXT	T1 NEXT Adj. Binder
T1.601 (7,13)	6	--	--	24	--
CSA (4)	6	24	--	24	--
CSA (6)	6	--	20	--	--
CSA (7)	6	10	--	10	--
Mid-CSA	3	--	--	--	10

The requirements for impulse noise and POTS interference testing are also defined.

In these documents, the electrical characteristics of all the impairments are defined. This allows impairment simulators to be used instead of introducing real impairments. *Figure 15* shows the typical set up for transceiver testing using an impairment simulator.

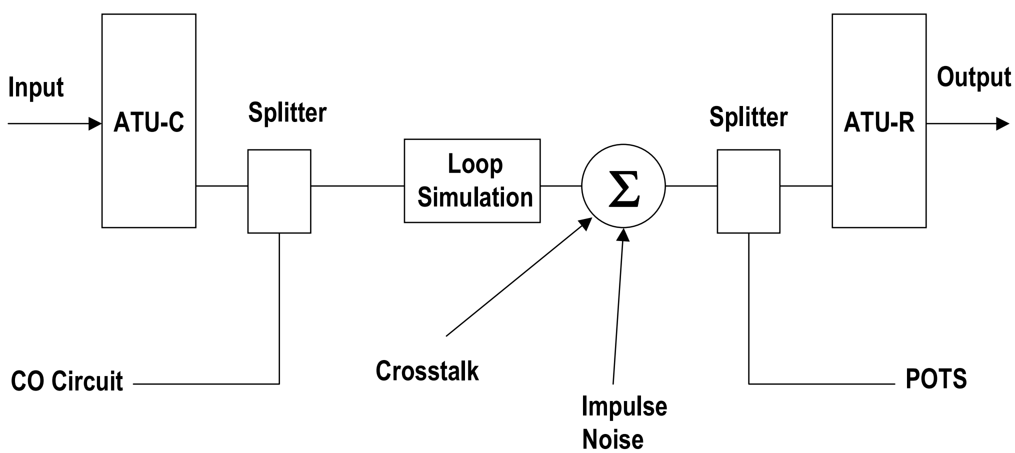


Figure 15. Impairment Simulation

As an example, *Table 6 on page 25* shows the results of tests that were run using the DLS TestWorks XPS Wireline Simulator. It shows the effect of various cable lengths on the trained speeds and the signal attenuation. Note that to simplify the test, no disturbers or impulse noise patterns were added. With the addition of noise, the speed will be lower because of the decreased signal-to-noise margin.

Table 6. DLS TestWorks XPS Wireline Simulator Test Results

Simulated Length (km)	Downstream Speed (kbps)	Downstream Attenuation (dB)	Upstream Speed (kbps)	Upstream Attenuation (dB)
0.5	7040	30.0	896	4.4
1	7040	30.0	896	9.2
2	7040	30.1	832	19.1
3	7040	43.5	704	28.6
4	7040	58.1	512	38.4
4.25	5792	59.4	448	40.8
4.5	4832	62.1	384	43.0
4.75	4064	63.9	320	46.1
5	3520	63.9	256	48.4

In cable modem testing, CableLabs also included impairment testing in the Interoperability Test Plan. In it, it specified that all tests should be executed twice – once in an active cable plant with minimal or no RF impairments and once in the same cable plant with a well-defined impairment CATV environment. The impairments are defined in terms of carrier-to-noise ratio, carrier-to-cross-modulation-ratio, amplitude ripple, burst noise and so on. With these impairments, the BER performance target is 10^{-8} when operating with carrier-to-noise ratio of at least 23.5 dB for 64 QAM and 30-33 dB for 256 QAM.

Conclusions

With increased interest in high-speed Internet access, both xDSL and cable modem technologies have seen widespread deployment and rapid growth. As more products appear on the market, it becomes very important for both equipment manufacturers and network implementers to test their equipment for conformance, interoperability and performance. This document highlights some of the unique testing issues in broadband access and presents a series of sample test cases. By thoroughly testing the equipment before deployment, equipment manufacturers can ensure that their products will meet or surpass market expectations. Similarly, network implementers can ensure that equipment deployed in the network can interoperate to provide a stable, maintainable, and efficient network for the users.

Glossary

2 Binary, 1 Quaternary (2B1Q)

A type of line encoding for transmitting 2 bits per symbol. 2B1Q is a 4-level PAM system used for HDSL/SDSL, S-HDSL, and ISDN BRI.

Active Service Flow

An admitted Service Flow from the CM to the CMTS which is available for packet transmission.

Admitted Service Flow

A Service Flow, either provisioned or dynamically signaled, which is authorized and for which resources have been reserved but is not active.

ADSL-Lite

ITU G.992.2 (G.lite). A form of ADSL which does not require a splitter but provides less performance. Downstream is limited to 1.5 Mbps max. vs. 8 Mbps for ADSL. Upstream is limited to 512 Kbps max. vs. 1.5 Mbps.

ADSL Terminal Unit Central Office (ATU-C)

An ADSL terminal near the central office or remote network node.

ADSL Terminal Unit Remote (ATU-R)

An ADSL terminal near the subscriber.

American National Standards Institute (ANSI)

A US standards body. The ANSI T1E1.4 committee covers specifications for ADSL and other DSL types.

Asymmetric Digital Subscriber Line (ADSL)

ITU G.992.1 (G.dmt), ANSI T1.413i2, ETSI ETR-328. A type of single-pair DSL with higher bandwidth in one direction than the other. Theoretical maximum speed is 14.9 Mbps but 8 Mbps is more typical for downstream direction; upstream direction speed can be up to 1.5 Mbps but 640 Kbps is typical. Can co-exist with POTs equipment. An ADSL requires a splitter whereas ADSL-lite requires no splitter but provides less performance (1 Mbps vs. 8 Mbps).

Asynchronous Transfer Mode (ATM)

A protocol for the transmission of a variety of digital signals using uniform 53 byte cells.

ATM Adaptation Layer 5 (AAL5)

Allows the transmission of variable length data frames using fixed-length ATM cells.

ATM Forum

A consortium of companies promoting common specifications for ATM-related protocols.

Backbone network

Core high bandwidth links concentrating traffic from access links.

Bandwidth Allocation Map

The MAC Management Message that the CMTS uses to assign transmission opportunities to CMs.

Baseline Privacy

A DOCSIS defined set of services providing for data encryption, using DES, within a cable system and, for protection against theft of services. DOCSIS 1.1 added the capability to use other encryption facilities such as RSA.

Bearer Channels

In the context of DSL, multiple streams of data may be distinguished as discrete channels, each of which is assigned a given proportion of the available bandwidth possibly influenced by QoS constraints.

Broadband

Communications operating at data rates above 1.5/2.0 Mbps.

Burst

In the context of cable technology, a series of slots emitted at one time by a cable modem toward the headend.

Cable Data Network (CDN)

Uses existing CATV networks to provide data as well as video.

Cable Modem (CM)

A modulator-demodulator device at a subscriber location which connects using radio frequencies over cable to a cable network headend. The customer computing equipment is normally connected via Ethernet or USB.

Cable Modem Termination System (CMTS)

Provides complementary functionality to the cable modems to enable data connectivity to a wide-area network. Located at the cable television system headend or distribution hub.

Cable Modem Termination System – Network Side Interface (CMTS-NSI)

The interface, defined in DOCSIS, between a CMTS and the equipment on its network side.

Cable Modem to CPE Interface (CMCI)

The interface, defined in DOCSIS, between a CM and CPE.

Cable Modem to Telephone Return Interface (CMTRI)

The voice-band modem interface to the PSTN used by certain cable modems for upstream traffic.

Cable Television Labs, Inc. (CableLabs)

A consortium of North/South American CATV operators currently promoting DOCSIS and other cable technology initiatives.

Carrier Serving Area (CSA)

Distances up to 12,000 ft. from a Carrier Office.

Carrierless Amplitude Modulation/Phase Modulation (CAP)

A type of modulation considered for ADSL. DMT has been adopted but some early ADSL equipment uses CAP.

Coder/Decoder (Codec)

Hardware or software used for conversion of analogue signals, often video or audio, to/from digital form for transmission or storage. Usually performs compression or other optimizations such as silence suppression.

Concatenation

Combining multiple small frames for transmission in order to reduce overhead due to lower communication layers.

Consumer ADSL (C-ADSL)

See *ADSL-Lite*.

Contention Slots

Slots reserved by the CMTS headend for any cable modem to use for upstream transmission. See *Bandwidth Allocation Map*. If more than one modem attempts to transmit during the same contention slots, none succeeds and they retry during future randomly selected contention slots. Normally used for short requests, often to request many reserved slots for a pending upstream transmission.

Crosstalk

A type of interference whereby signals on one wire affect signals on another wire. Far-end cross talk (FEXT) occurs at the receiving end. Near-end cross talk (NEXT) occurs at the transmitting end.

Customer Premises Equipment (CPE)

Equipment at the end user's premises (e.g. PC, router, etc.); may be provided by the end user or the service provider.

Data Encryption Standard (DES)

An encryption standard developed by IBM and adopted by the US government.

Data Link Layer

Layer 2 in the Open System Interconnection (OSI) architecture; the layer that provides services to transfer data over the transmission link between open systems. Comprised of the Logical Link Sub-Layer and the Media Access Control Sub-layer.

Data-Over-Cable-Service Interface Specifications (DOCSIS)

A set of standards defining interfaces for the CMTS headend, cable plant, and remote cable modem plus management and security. Defines Physical and MAC layers as well as data delivery facilities including security and QoS. Defines IEEE 802 frame encapsulation with provisions for later incorporation of ATM.

Demodulator

Recovers a digital signal encoded for transmission on an analogue carrier. Different forms of modulation can be used (e.g. QPSK, QAM-64, QAM-256, DMT, etc.). May be incorporated with additional functions such as MPEG frame synchronization (cable modem downstream) and error correction (e.g., Reed Solomon).

Digital Audio Video Council (DAVIC)

A Swiss-based consortium that promoted the DVB (Digital Video Broadcasting) project. This group developed a competitor to DOCSIS prior to DOCSIS. DAVIC/DVB encapsulates ATM cells directly, whereas DOCSIS currently only provides for IEEE 802 frame encapsulation although it is expected to eventually support ATM. Although DAVIC's mandate has expired, their definitions have been adopted by many European cable operators. DOCSIS 1.1 includes provisions, common known as "Euro-DOCSIS," to allow interoperability with the deployed cable plants and it is expected that DOCSIS will dominate.

Digital Loop Carrier (DLC)

A PSTN distribution system with fiber links from the carrier office to a distribution node from which conventional analogue phone loops emanate to individual subscribers.

Digital Signal 0 (DS-0)

The North American Digital Hierarchy signaling standard for transmission at 64 kbps. Also the worldwide standard transmission rate (64 kbps) for PCM digitized voice channels.

Digital Signal 1 (DS-1)

The North American Digital Hierarchy signaling standard for transmissions at 1.544 Mbps. Supports 24 simultaneous DS-0 signals. The term is often used interchangeably with T-1, although DS-1 signals may be exchanged over other transmission systems.

Digital Signal 3 (DS-3)

The North American Digital Hierarchy signaling standard for transmissions at 44 Mbps.

Digital Signal Processor (DSP)

High speed hardware designed for rapid conversion, or other processing, of digital signals encoded in analogue form.

Digital Subscriber Line Access Multiplexor (DSLAM)

A concentrator that connects a number of DSL subscriber lines providing either bridge or router services between the lines and/or other types of network interface (e.g., ATM, Ethernet, etc).

Digital Subscriber Line/Loop (DSL)

One or more wire pairs from a carrier office (or DLC node) to a subscriber. A DSL does not have a POTS 4 KHz filter and is therefore capable of much higher bandwidths. A DSL may or may not be conditioned to remove taps. It must not have any loading coils (devices to reduce improve POTS signal quality over long distances). More generally, DSL is the overall name for a set of modem-like technologies that overlay a digital data stream over a high speed analogue signal (see *ADSL, HDSL*).

Digital Video Broadcasting (DVB)

See *DAVIC*.

Discrete Multitone (DMT)

A type of modulation adopted for ADSL. It divides a frequency range into discrete sub-channels, each of which is tuned with a separate modulation scheme (e.g., QAM-16) to encode digital signals. Each sub-channel may vary in capacity depending upon noise sources that coincide with it. In the context of ADSL, 256 4.3125KHz sub-channels may be defined.

Distribution Hub

A location in a cable television network which performs the functions of a Headend for customers in its immediate area, and which receives some or all of its television program material from a Master Headend in the same metropolitan or regional area.

Downstream

In cable television and DSL, the direction of transmission from the central office access concentrator to the subscriber. A downstream data path may be a separate physical connection or may share a physical medium with the upstream data path; for example, via Time Division Multiplexing or Frequency Division Multiplexing.

In the context of cable technology, the downstream data path is dedicated to headend transmissions operating in the rage of 50 MHz to 860 MHz or more. It is channelized into 6 MHz channels with per subscriber net bandwidth typically around 3-10 Mbps.

In the context of DSL technology, the downstream data path varies. For ADSL, it is generally between 200 KHz and 1 MHz with a net effective bandwidth of 1.5-8 MHz. For other forms of DSL, it may be on separate wires with much higher bandwidths.

Drop Cable

Coaxial cable that connects to a residence or service location from a directional coupler (tap) on the nearest coaxial feeder cable.

E1

The European equivalent of T1 but operating at 2.048 Mbps.

Echo Cancellation

When transmitting a signal, some of the signal energy may be reflected back to the transmitter. For some types of full duplex communication, this will interfere with a real signal being sent to the transmitter. A full duplex device can eliminate some of this noise in a received signal by applying a correction signal derived from its transmitted signal.

Electronic Industries Association (EIA)

A voluntary body of manufacturers that prepares and publishes standards.

Euro-DOCSIS

Extensions to DOCSIS to handle the European cable plan standard, which uses 8 MHz channels instead of 6 MHz, and allocates 5-65 MHz instead of 5-42 MHz for upstream transmission. See *DAVIC*.

European Telecommunications Standards Institute (ETSI)

A European standards body. ETSI ETR-328 is the full rate European ADSL specification.

Far-end Cross Talk

See *Crosstalk*.

Feeder Cable

Coaxial cables that run along streets within the served area and connect between the individual taps which serve the customer drops.

Fiber To The Curb (FTTC)

Fiber that terminates very near customer premises and then connects to one customer over copper.

Fiber To The Home (FTTH)

Fiber that terminates on customer premises.

Fiber To The Building (FTTB)

Fiber that terminates on customer premises.

Fiber To The Neigborhood (FTTN)

Fiber that terminates to a point near customer premises, many of which are then served via copper. Examples include HFC and DLC.

Forward Error Correction (FEC)

Redundant bits are included with a transmission in order for a recipient to recover from some number of bit errors in the transmission. The alternative is simple error detection without correction, in which case the information is either lost/ignored or a re-transmit request is returned by the recipient. For real-time data, detection and re-transmission requests are often not suitable due to excessive delays. FEC attempts to avoid such delays. An example is Reed Solomon coding, which in the case of cable downstream traffic, adds 16 bytes to 188 bytes of data, allowing up to 8 errors to be corrected.

Fragmentation

In the context of cable technology, breaking up large frames in order to permit higher priority frames to be transmitted. Also used to transmit large frames without constraining the bandwidth allocation strategies to a minimum allocation size.

Frequency-Division Multiplexing (FDM)

Multiple data streams, possibly in different directions, sharing a physical medium by isolation within reserved frequency ranges.

G.dmt

See *Asymmetric Digital Subscriber Line (ADSL)*.

G.hs

ITU-T G.994.1, Handshake procedures for ADSL.

G.lite

See *ADSL-Lite*.

G.test

ITU-T G.996.1, Test procedures for DSL.

Headend

The central location on the cable network that is responsible for injecting broadcast video and other signals into the downstream direction.

High-rate Digital Subscriber Line (HDSL)

ITU G.991. A type of DSL capable of T1 bandwidths. It requires no repeaters up to 12,000 ft. and uses four wires. It is strictly digital, with no provision for co-existence with POTS equipment on the same line. E1 flavors are also supported. It uses 2B1Q encoding, which is less noisy than T1's AMI encoding.

High-rate Digital Subscriber Line 2 (HDSL2)

HDSL2 is like HDSL, but uses one pair of wires and is more tolerant to noise. Multi-pair implementations can exceed 12,000 ft without repeaters.

Hybrid Fiber/Coax (HFC) System

A broadband bi-directional shared-media transmission system using fiber trunks between the headend and the fiber nodes, and coaxial distribution from the fiber nodes to the customer locations.

IEEE 802.14

An IEEE effort to promote cable modem technology. It contributed the physical layer to DOCSIS. The document is now defunct.

Institute of Electrical and Electronic Engineers (IEEE)

A voluntary organization which, among other things, sponsors standards committees and is accredited by the American National Standards Institute. IEEE Project 802 drives many network standards oriented to the physical and logical link layers.

Interactive Set-Top Box

See *Set-Top Box*.

Interleaving

A process whereby multiple frames to be transmitted are divided into sub-blocks that are then sent intermixed. If forward error correction is applied to each frame, then an error burst that affects multiple sub-blocks from different frames has less likelihood of actually losing data from any one frame.

Integrated Services Digital Network (ISDN)

Digital data and voice service on a common link. Basic Rate Interfaces provide 64 Kbps or 128 Kbps. Primary Rate Interfaces provide T1 and higher speeds.

Integrated Services Digital Network DSL (IDSL)

A type of DSL that supports ISDN customer equipment working over a DSL at rates of 128 Kbps or 144 Kbps. Unlike ISDN, digital voice is not supported. Unlike ADSL, it cannot coexist with POTS equipment.

International Electrotechnical Commission (IEC)

An international standards body.

International Organization for Standardization (ISO)

An international standards body, commonly known as the International Standards Organization. It is known for its seven layer OSI model of tiered communication systems.

International Telecommunications Union (ITU)

A Swiss-based standards organization comprised of national governments and international companies. ITU G.991, G.992.1, G.992.2 cover HDSL, ADSL, and ADSL-lite respectively.

Internet Engineering Task Force (IETF)

An open standards organization driving the Internet RFC (Request For Comment) process. The IPCDN (IP over Cable Data Network) working group has produced various RFCs dealing with management SNMP MIBs (Simple Network Management Protocol Management Information Base) in support of DOCSIS.

Internet Group Management Protocol (IGMP)

A network-layer protocol for managing multicast groups on the Internet.

ITU G.991

See *HDSL*.

Lifeline POTS

A minimal telephone service designed to extend a “lifeline” to the telephone system in case of emergency, particularly when electric power is lost.

Line Code

Methods for transmitting digital information by emitting discrete pulses instead of using modulation of a carrier wave (e.g. 2B1Q, NRZ, Bipolar Alternate Mark Inversion, Manchester).

Loading Coils

Inductors placed in series with the cable at regular intervals in order to improve the voice-band response; removed for DSL use.

Local Multichannel Distribution Services (LMDS)

An antenna-based communication service. Reaches 2-3 miles; up to 54 Mbps downstream; requires line of sight.

Logical Link Control (LLC)

The LLC layer is the upper sub-layer of the OSI Data Link layer. It controls the assembling of data link layer frames and their exchange between data stations, independent of how the transmission medium is shared.

Loop

A twisted-pair copper telephone line connecting from the PSTN to a client's premises. Loops may differ in distance, diameter, age, and transmission characteristics depending on the network.

MAP

See *Bandwidth Allocation Map*.

Master Headend

A headend that collects television program material from various sources by satellite, microwave, fiber and other means, and distributes this material to Distribution Hubs in the same metropolitan or regional area. A Master Headend may also perform the functions of a Distribution Hub for customers in its own immediate area.

Media Access Control (MAC)

The MAC layer is the lower sub-layer of the OSI Data Link layer. It mediates access to and use of the underlying physical layer. For example, it handles contention resolution for a shared medium such as Ethernet or the upstream cable modem data path (headend only). In the context of cable modem technology, the MAC also provides for signal power and timing adjustments (see *Ranging*).

Media Access Control (MAC) Address

The "built-in" hardware address of a device connected to a shared medium.

Mini-Slot

A "mini-slot" is an integer multiple of 6.25 microsecond increments.

Modulator

Converts a digital signal for transmission on an analogue carrier. Different forms of modulation can be used (e.g. QAM-64, QAM-256, DMT, etc). May be incorporated with additional functions (e.g. error correction [Reed Solomon]).

Moving Picture Experts Group (MPEG)

A voluntary body that develops standards for digitally-compressed moving pictures and associated audio. Also, a digital representation format for video.

MPEG Transport Stream (MPEG-TS)

An ITU-specified encoding for transmission of MPEG video data. A 188-byte block includes a header and payload data. In addition, a 16 byte Reed Solomon error correction pad is prepended.

MPEG-1/MPEG-2

MPEG-1 and MPEG-2 are specifications for encoding and compressing motion video.

MSAP

MAC Service Access Point.

Multimedia Cable Network System (MCNS)

TCI, Time Warner Cable, Cox, Comcast, Cable Labs, and others formed MCNS. They developed DOCSIS which is now managed by CableLabs.

Multipoint Multichannel Distribution Services (MMDS)

An antenna-based communication service. Reaches 20-30 miles; up to 54 Mbps downstream; requires line of sight.

Narrowband Network

A switching system for data rates at or below 1.5/2.0 Mbps.

National Cable Television Association (NCTA)

A voluntary association of cable television operators which, among other things, provides guidance on measurements and objectives for cable television systems in the USA.

National Television Systems Committee (NTSC)

A committee that defined the analog color television broadcast standard used today in North America.

Near-end Cross Talk

See *Crosstalk*.

Network Layer

Layer 3 in the OSI architecture; the layer that provides services to establish a path between open systems.

Open Systems Interconnection (OSI)

A framework of ISO standards for communication between different systems made by different vendors. According to OSI, the communication process is organized into seven different categories that are placed in a layered sequence based on their relationship to the user. Each layer uses the layer immediately below it and provides a service to the layer above. Layers 7 through 4 deal with end-to-end communication between the message source and destination, and layers 3 through 1 deal with network functions.

OpenCable

An MCNS and Cable Labs initiative principally intended to define common specifications for set-top boxes. The focus is on inter-operability and content security (e.g., movie copy protection).

PacketCable

An MCNS and Cable Labs initiative principally intended to carry packetized voice and fax over DOCSIS capable cable systems. Services include voice mail, call placement, call management, PSTN interfaces (SS7), and other functions common to traditional voice carriers.

Passband Filter

A filter that allows a selected range of frequencies to be transmitted. In the context of POTS implementation, a 4 KHz passband filter is installed at the carrier office of analogue local loops to prevent high frequency signals from disrupting carrier equipment.

Payload Header Suppression (PHS)

The suppression of the header in a payload packet (e.g., the suppression of the Ethernet header in forwarded packets). In the context of cable technology, a bit mask identifies bytes that need not be sent since they are the same as in the preceding packet.

Physical (PHY) Layer

The lowest layer of the OSI communications architecture. It is concerned with the electrical and signaling characteristics of the actual physical medium to transmit and receive data.

Physical Media Dependent (PMD) Sublayer

A sublayer of the Physical Layer concerned with transmitting bits or groups of bits over particular types of transmission link between open systems and that entails electrical, mechanical ,and handshaking procedures.

Plain Old Telephone System (POTS)

Traditional analogue telephone service using the voice band. Sometimes used as a descriptor for all voice-band services.

Point to Point Protocol (PPP)

A protocol used to encapsulate various network protocols. PPP is typically used to interconnect two networks, or a remote user and a network, over a link or circuit that is accessible to only two parties (typically a serial link).

Primary Service Flow

All CMs have a Primary Upstream Service Flow and a Primary Downstream Service Flow. They ensure that the CM is always manageable and they provide a default path for forwarded packets that are not classified to any other Service Flow.

Provisioned Service Flow

A Service Flow that has been provisioned as part of the Registration process, but has not yet been activated or admitted. It may still require an authorization exchange with the CMTS prior to admission.

Public Switched Telephone Network (PSTN)

An umbrella term that represents the carriers that make up the telephone services.

Pulse Amplitude Modulation (PAM)

A type of modulation that encodes amplitude and polarity to encode digital signals. PAM is the system used for HDSL/SDSL, S-HDSL, and ISDN BRI.

Quality Of Service (QoS)

In communications, an umbrella term referring to the application of constraints to favor certain types of traffic and, potentially in some contexts, ensure a given level of service. Typically intended to constrain errors, latency, or jitter while ensuring a set bandwidth.

Quadrature Amplitude Modulation (QAM)

A method of modulation that uses the amplitude and phase of a carrier to encode digital data. QAM-16 encodes 4 bits per "symbol;" QAM-256 encodes 8 bits per "symbol."

Quadrature Phase-Shift Keying (QPSK)

A method of modulation that uses four phase states to encode two digital bits. Used for upstream signaling in cable modems.

Radio Frequency (RF)

In cable television systems, this refers to electromagnetic signals in the range 5 to 1000 MHz.

Ranging

The process whereby a cable modem and the CMTS headend negotiate the appropriate signal power levels for the modem to use and also establish a signal delay offset (due to cable distances) so that transmissions from all modems can be synchronized (to establish a common reference for slot times).

Ranging Slots

Slots reserved by the CMTS for cable modems to adjust their power and signal delay offsets. A CMTS allocates a relatively long initial range interval for a newly activated cable modem to establish a reference. Thereafter, the CMTS will then reserve "station maintenance" intervals for a specific modem for finer re-adjustments.

Rate Adaptive ADSL (R-ADSL)

A form of ADSL that adjusts bandwidth depending upon line conditions. R-ADSL is no longer relevant since ADSL presently provides for dynamic adjustments.

Repeater

A device used to regenerate digital signals and restore signal quality to support longer cable distances. Used in DSL and T1 technologies (and others).

Reserved Slots

Slots reserved by the CMTS headend for a given cable modem to use for upstream transmission. See *Bandwidth Allocation Map*. Normally used in longer transmissions where the slot allocation was previously requested possibly via contention slots.

Rivest-Shamir-Adleman (RSA)

The creators of a public-key cryptography algorithm.

Service Flow

A MAC-layer transport service that provides unidirectional transport of packets from the upper layer service entity to the RF and prioritizes traffic according to QoS traffic parameters defined for the flow.

Service Flow Identifier (SFID)

An identifier assigned to a service flow by the CMTS [32 bits].

Service Flow Reference

A message parameter in Configuration Files and Dynamic Service MAC messages used to associate Classifiers and other objects in the message with the Service Flow Encodings of a requested service flow.

Service Identifier (SID)

A service flow identifier assigned by the CMTS (in addition to a Service Flow Identifier) to an Active or Admitted Upstream Service Flow [14 bits].

Set-Top Box

Provides basic interactive functionality to a cable subscriber facility. Output is displayed to television; input is from a keyboard and/or pointing device. Can incorporate a cable modem and may use POTS for a return path. Can also be used for access to digital television signals.

Simple Network Management Protocol (SNMP)

A network management protocol of the IETF.

Slot

In the context of cable modem technology, a slot is a time period that is a power-of-two multiple of 6.25 microseconds during which upstream transmission take place. See *Reserved Slots*, *Contention Slots*, and *Ranging Slots.*

Spectrum Management

The process whereby a CMTS headend allocates the upstream frequencies for use by individual cable modems.

Splitter

In the context of some DSL services, a device that separates frequencies below 4 KHz (with a wide guard band) from high frequency digital data traffic to allow a line to be used with digital equipment as well as POTS equipment. The splitter may be integrated into the ATU, physically separated from the ATU, or divided between high pass and low pass, with the low pass function physically separated from the ATU.

Splitter-less ADSL

See *ADSL-lite*.

Superframe

In the context of ADSL, 68 varying-length frames of data. One superframe is sent every 17 ms and the available bandwidth determines its capacity.

Symmetric DSL (SDSL)

A type of DSL that supports speeds up to 1 Mbps at 11,500 ft over one pair. SDSL is not as relevant as HDSL2. May be used for fractional T1 service as permitted by distance.

Synchronous Transfer Mode (STM)

A channelized communications technology where channels reserve bandwidth whether or not there is data to transmit. For example, T1. STM contrasts with ATM.

T1

One implementation of DS-1 services utilizing four wires and Bipolar Alternate Mark Inversion (AMI) encoding. Requires repeaters every 6,000 ft.

Tick

6.25 microsecond time intervals that are the reference for upstream mini-slot definition and upstream transmission times.

Time Division Multiplexing (TDM)

Multiple data streams, possibly in different directions, sharing a physical medium by isolation within reserved time intervals.

Training

The process whereby modems negotiate transmission parameters in order to optimize the use of a circuit when faced with various types of noise or interference. Training may recur to adjust to changing conditions.

Transmission Control Protocol (TCP)

A transport-layer Internet protocol that ensures successful end-to-end delivery of data packets without error.

Transmission Convergence Sublayer

A sublayer of the Physical Layer that provides an interface between the Data Link Layer and the PMD Sublayer.

Transmission Link

The physical unit of a subnetwork that provides the transmission connection between adjacent nodes.

Transmission Medium

The material on which information signals may be carried (e.g., optical fiber, coaxial cable, and twisted-wire pairs).

Transmission System

The interface and transmission medium through which peer physical layer entities transfer bits.

Transmit Opportunity

A number of slots available to a cable modem for upstream transmission. Slots may be either reserved or contention slots.

Transport Stream

In MPEG-2, a packet-based method of multiplexing one or more digital video or audio streams that have one or more independent time bases, into a single stream.

Trivial File-Transfer Protocol (TFTP)

An Internet protocol for transferring files without the requirement for user names and passwords typically used for automatic downloads of data and software.

Trunk Cable

Cables that carry the signal from the headend to groups of subscribers. The cables can be either coaxial or fiber depending on the design of the system.

Tuner

A cable modem component used to receive and transmit channelized RF signals.

Twisted Pair

Two wires twisted with each other. Normally many pairs are combined inside a common sheath. Twisting reduces some types of electrical interference.

Upstream

In the context of DSL and cable broadband technology, the data direction heading away from the edge of a network towards the core of the network. An upstream data path may be a separate physical connection or may share a physical medium with the downstream data path; for example, via Time Division Multiplexing or Frequency Division Multiplexing.

In the context of cable technology, the upstream data path is a headend assigned channel in the range of 5 MHz to 42 MHz (65 MHz Europe) with per subscriber net bandwidth typically around 500 Kbps to 3 Mbps.

In the context of DSL technology, the upstream data path varies. For ADSL, it is generally between 30 KHz and 140-200 KHz with a net effective bandwidth of up to 640 kbps. For other forms of DSL, it may be on separate wires with much higher bandwidths.

Very-high-rate Digital Subscriber Line (VDSL)

A type of DSL capable of 52 Mbps bandwidth over shorter distances using copper. Requires DLC (optical) distribution to achieve useful distances. VDSL can be symmetric or asymmetric and can coexist with POTs equipment on the line. It uses one twisted pair, over which it can transmit and receive concurrently using Time or Frequency Division Duplexing.

Voice Band

A frequency range of 0 to 4 KHz that is used for analogue (voice, fax, data) signaling in conventional POTS.

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