Copper Access

1. DSL
   Twisted copper pairs includes advances with ADSL2+ (ITU-T G.992.5), SHDSL (ITU-T G.991.2) as well as the recent proposals of ADSL2++ and VDSL2.

2. COAX
   Coax/CATV updates includes DOCSIS 2.0 (Data over Cable Service Interface Specification) and ITU-T (J.122).

3. PLC
   Powerline Carrier (PLC) includes Powerline telecommunication (PLT) and Broadband over Power Line (BPL) with updates from the ITU Radio Communication Sector (ITU-R) Sub Working Group (SWG) 6E1.
Cable/DSL Share in Top Ten Countries

Source: Point-Topic

DSL Deployment (% per 100 phone lines)

South Korea 30.4
Taiwan 18.1
Iceland 18.0
Hong Kong 17.2
Belgium 13.8
Japan 13.0
Israel 11.6
Singapore 11.4
Denmark 11.1
Canada 10.2

Source: Point-Topic
1. DSL

- Asymmetric Digital Subscriber Line
- ANSI T1.413-1998
- G.992.1 = G.dmt = 8.1/0.8 Mbps (down/up) using 256 bins
- G.992.2 = G.lite = 1.5/0.5 Mbps using 128 bins
- G.992.1 with S=1/2 line coding yielding 12 Mbps
- G.992.3 = G.dmt.bis (July2002) aka ADSL2
- G.992.3 Annex L = Reach Extended RE-ADSL2 (Oct2003)
- G.992.4 = G.lite.bis (May2002)
- G.992.5 = ADSL2plus = 24 Mbps at 5,000 feet (Jan2003)
- ADSL4 = 52 Mbps proposed quad spectrum (ADSL2++)

ITU-T Updates

G.992.5 = ADSL2plus

DMT ADSL

- 4kHz low pass filter (LPF) for voice
- sub-carrier spacing for discrete multitones (DMT)
Three Down Stream (DS) Speeds

1. Theory
   - Possible 256 bins, 12 Mbps max

2. Actual
   - Actual for the copper local access loop
   - Perhaps 188 bins, 9.6 Mbps max
   - Some bins disabled by the copper loop
   - Will depend upon “bits per bin” loading

3. Tariff
   - The service you requested, purchased
   - Perhaps 140 bins, 1.5 Mbps max
   - Some bins disabled by the service provider

Quad Spectrum

- Extend the DS (Downstream) bins to 3.75 MHz
- Widen the US (Upstream) from 138kHz to 276 kHz
- Enhance the bit loading beyond 15 bits per bin
G.992.5 Upstream PSD (ADSL2plus)

Power Spectral Density (PSD)

-21.5 dB/octave
-97.5 peak
+15 dBm/Hz
0-4 kHz

-34.5 dBm/Hz peak PSD
-72 dB/octave
-10 dB/dec

-92.5 dBm/Hz
-93.2 dBm/Hz

POTS
Passband 26 – 138 kHz

G.992.5 Downstream PSD (ADSL2plus)

-36 dB/octave
-4.63 dB/dec

-36.5 dBm/Hz peak PSD
-3 dB/dec

-37.5 peak
+15 dBm/Hz
0-4 kHz

-42 dBm/Hz
-44.2 dBm/Hz

Passband 138 – 2208 kHz
ANSI and ITU (G.dmt)

- ANSI T1.413 - 1998
- ITU-T G.992.1-1999 = ADSL (ADSL1)
- ITU-T G.992.3-2002 = ADSL2 (July 2002)
- ITU-T ADSL includes localization for different countries;
  - Annex A with POTS
  - Annex B with ISDN
  - Annex C with TCM-ISDN for Japan
  - Annex H for Japan
- G.992.1 has an enhanced activation compared to ANSI called G.994.1 (G.hs – handshake). Instead of a single tone being used to indicate optional features supported by a DSL modem, several tones digitally transmit the same information for a more robust startup.
- G.997.1 (G.ploam) -- management

G.992.3 (G.dmt.bis) = ADSL2

- ITU-T Study Group 15, Question 4 (SG15-Q4)
- May 2002 consent, July 2002 approved
- Technical freeze on ADSL
- “.bis” means “other” or second version
- Major changes in ADSL2 …
  - Improved bit rate in the downstream
  - Mandatory Trellis Code
  - Line Diagnostics
  - Reduced Power
  - All Digital Mode
G.992.3 (ADSL2) - Bonding

- ADSL2 provides support for inverse multiplexing
- Bonding of multiple copper pairs for transport of a single ATM stream (ATM Forum Standard af.phy-0086.001 Inverse Multiplexing for ATM (IMA), Version 1.1)
  - 32 Mbps on 4 bonded pairs
  - 24 Mbps on 3 bonded pairs
  - 16 Mbps on 2 bonded pairs
G.992.3 (ADSL2) – Speed Change

- Improved bit rate
  - Was 2-15 bits, now also 1-bit signal constellations
  - four-dimensional, 16-state trellis-coded and 1-bit quadrature amplitude modulation (QAM) constellations
  - Results in a 96-192 kbps greater downstream
- Reduced framing overhead for faster transfers
- *Adaptable pilot tone* location (carrier #64 = 276kHz)
  - Will result in better clocking
- Mandatory Trellis coding and Reed Solomon RS=15
- Explicit rate negotiation
  - Will be good for multi-vendor configurations
  - Better tone reordering for RFI robustness

G.992.3 (ADSL2) – Rate & Reach

21.5 kft = 6.5 km

Diagram source: www.aware.com

COPPER-15, COPPER-16
G.992.3 (ADSL2) – SRA

- ADSL2 can dynamically adapt to changes in line conditions:
  - Crosstalk from other DSL in the same cable
  - Narrow band AM (radio) disturbers
  - Temperature changes
  - Water in the cable bundle
- Uses online reconfiguration (OLR) when SNR changes
- SRA is important for video to avoid tiling (pixelization)
- Seamless rate adaptation (SRA) enables the transceiver to monitor line conditions and dynamically adapt the data rate “seamlessly”, i.e. without bit errors or requiring a service interruption for retraining

G.992.3 (ADSL2) - Digital Mode

- All digital mode (no POTS, could have derived voice)
- About 256 kbps additional up stream data rate
- 0-26 kHz used for digital transmission not voice
- This option is not suitable for line sharing
ADSL2 DELT

- DELT (Dual-Ended Line Test)
- Defined by the ADSL2 (G.992.3)
- Enables the measurement of line conditions at both ends without dispatching maintenance technicians to attach test equipment to the end of the line.
- The information helps to isolate the location and the sources of impairments caused by crosstalk, radio-frequency interference and bridge taps.
- Data Collection is "DELT physical-layer technology"
- Data Processing is "Loop Identification"
- SELT (Single-Ended Line Test) future option

SELT/DELT Comparison

<table>
<thead>
<tr>
<th>Feature/requirement</th>
<th>DELT support</th>
<th>SELT support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loop topology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loop segment gauge</td>
<td>Yes (longer loops)</td>
<td>Yes (shorter loops)</td>
</tr>
<tr>
<td>Bridge tap(s) location</td>
<td>Yes (longer loops)</td>
<td>Yes (shorter loops)</td>
</tr>
<tr>
<td>Bridge tap(s) gauge</td>
<td>Yes (longer loops)</td>
<td>Yes (shorter loops)</td>
</tr>
<tr>
<td>Loop Condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loop condition</td>
<td>Not applicable</td>
<td>Yes</td>
</tr>
<tr>
<td>Loop condition</td>
<td>Not applicable</td>
<td>Yes</td>
</tr>
<tr>
<td>Broadband loop noise characteristics</td>
<td>Yes</td>
<td>Over direction</td>
</tr>
<tr>
<td>Broadband loop interfernce analysis</td>
<td>Option</td>
<td>Option</td>
</tr>
<tr>
<td>Requires line terminating CPE</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Requires dedicated or switched DSLAM port</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Required layer technology standardized</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Loop identification technology standardized</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

**Note:** SELT (Single-ended line testing) DELT (Dual-ended line testing)
G.992.3 (ADSL2) – Low Power

- L0 is ADSL2 full power mode
- L2 is low power mode at the ATU-C (DSLAM) while idle will result in better power especially for remote DLC (Digital Loop Carrier) configurations
- L3 is low power mode at the ATU-R (user) and ATU-C enables the modem to sleep when information is not being transmitted (e.g. overnight) – it takes 3 seconds to come out of L3 (sleep mode)
- Ability to disable tones to aid spectral compatibility
- Extended training intervals
- Power back off during startup

G.992.3 (ADSL2) – Ethernet

- ADSL2 includes a packet mode transmission convergence layer (PTM-TC) that enables connection of ADSL2 modems to packet services (Ethernet)
- Extensive configuration capability for PTM-TC with configuration of …
  - latency
  - bit error rate
  - minimum/maximum data rate to meet packet protocol requirements
Reach-Extended ADSL

- G.992.3 Annex L
- Approved November 2003

- RE-ADSL2 performance improvements result from new power spectral density (PSD) masks designed to improve data rates on extra-long phone lines
- For downstream data rate of 384 kbps, results in 20%
- RE-ADSL2 is expected to operate as an alternative mode of an ADSL2 or ADSL2+ chipset that a carrier can choose to activate for particular customers

RE-ADSL2 (Down Stream Rate)

- 500 kbps at 18,500’
- 18,500’ = 5.6 km
- 384 kbps at 28,000’
- 28,000’ = 8.5 km
- RE is adding ½ km
- 1,500’ = 0.460 km
- 26 AWG
- 12 other ADSL
G.992.5 (ADSL2+)

- 24 Mbps possible with 512 bins up to 2.2 MHz

G.992.5 (ADSL2+)

- Possible to reduce cross talk by using different bins for different users
- Possible to mix ADSL2 (1.1 MHz) with ADSL2+ (2.2 MHz)
Annex Summary

<table>
<thead>
<tr>
<th>ANNEX</th>
<th>TYPE</th>
<th>#1 - 5 Bins</th>
<th>#6 - 31</th>
<th>#32 - 64</th>
<th>#65 - 255</th>
<th>#256 - 512</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (NA, EU, Asia)</td>
<td>POTS</td>
<td>POTS</td>
<td>UP</td>
<td>DOWN</td>
<td>DOWN</td>
<td>DOWN</td>
</tr>
<tr>
<td>B (Germany)</td>
<td>ISDN</td>
<td>ISDN</td>
<td>UP</td>
<td>DOWN</td>
<td>DOWN</td>
<td>DOWN</td>
</tr>
<tr>
<td>C (Japan)</td>
<td>TCM-</td>
<td>POTS</td>
<td>UP</td>
<td>DOWN</td>
<td>DOWN</td>
<td>N/A</td>
</tr>
<tr>
<td>I (Japan ADSL)</td>
<td>TCM-</td>
<td>POTS</td>
<td>UP</td>
<td>DOWN</td>
<td>DOWN</td>
<td>DOWN</td>
</tr>
<tr>
<td>I (Japan ADSL2)</td>
<td>POTS</td>
<td>UP</td>
<td>UP</td>
<td>DOWN</td>
<td>DOWN</td>
<td>N/A</td>
</tr>
<tr>
<td>J (All Digital)</td>
<td>ISDN</td>
<td>UP</td>
<td>UP</td>
<td>UP</td>
<td>DOWN</td>
<td>DOWN</td>
</tr>
<tr>
<td>L (RE-ADSL2)</td>
<td>POTS</td>
<td>POTS</td>
<td>UP</td>
<td>DOWN</td>
<td>DOWN</td>
<td>N/A</td>
</tr>
<tr>
<td>M (ADSL2+)</td>
<td>More Upstream</td>
<td>POTS</td>
<td>UP</td>
<td>UP</td>
<td>DOWN</td>
<td>DOWN</td>
</tr>
</tbody>
</table>

Automode

1. ADSL2 would connect at 690 kbps for CPE at 18,000 feet (4.5 km). Instead …
2. ADSL2/ADSL2+ CO collects loop data during initialization and training
3. Automode determines RE-ADSL2 is the best configuration based on line conditions
4. DSLAM configures customers port for RE-ADSL2 mode
5. CPE line at 1.1 Mbps (a 160% improvement over ADSL1)
Summary of Rate/Reach

- 2.4 km, 8 kft
- 4.3 km, 14 kft
- 3.0 km, 10 kft

DSM (Dynamic Spectrum Mgmt)

- **DSM level 0**
  - No coordination
- **DSM level 1**
  - Distributed multi-user power allocation
  - Implementation of Iterative Water Filling (IWF)
- **DSM Level 2**
  - Centralized multi-user power allocation
  - Optimal Spectrum Management (OSM)
- **DSL Level 3**
  - Multi-user detection
  - Also called vectoring
SHDSL

- Single-Pair High-bit-rate DSL (SHDSL)
- 16 level TC-PAM line coding
- Trellis Coded Pulse Amplitude Modulation (TC-PAM)
- ITU G.991.2 approved April 2001 (was G.shdsl)
  - 2-wire (2.36/2.36) ... 192 kbps steps
  - 4-wire (4.7/4.7) ... 384 kbps steps
- STU-R connects to STU-C
- Very good spectral compatibility with other services
- Some vendors are providing SHDSL over POTS

VDSL2

- Very-High-Data-Rate Digital Subscriber Line
- Standards track
- Downstream rates:
  - 12.96 Mbps (4,500 ft.– 1500m)
  - 25.82 Mbps (3,000 ft.– 1000m) = FTTN (Fiber-to-the-Node)
  - 51.84 Mbps (1,000 ft. – 300m) = FTTC (Fiber-to-the-Curb)
- Upstream rates from 1.6 to 2.3 Mbps
- Symmetric rate (13 Mbps) possible
- Simpler than ADSL
  - Shorter lines, fewer transmission constraints
  - Ten times faster
- Enables multiple video streams
- HDTV compatible (19 Mbps or 10 Mbps compressed)
**VDSL2 Spectrum**

- **Frequency Plan 998**
  
<table>
<thead>
<tr>
<th>Downstream</th>
<th>Upstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>138 kHz – 3.75 MHz</td>
<td>3.75 MHz – 5.2 MHz</td>
</tr>
<tr>
<td>5.2 MHz – 8.5 MHz</td>
<td>8.5 MHz – 12.0 MHz</td>
</tr>
</tbody>
</table>

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**Cable/DSL Split as of 31 Dec 2003**

- **Worldwide**
  
  - 64.1 Million / DSL (+32.1% in 2H 2003)
  - 36.8 Million / CATV (+18.2% in 2H 2003)

- **Canada**
  
  - 2.2 M / DSL (+16.2%)
  - 2.5 M / CATV (9.9%)

- **USA**
  
  - 9.3 M / DSL (+24.8%)
  - 15.8 M / CATV (+18.0%)
DSL Forum Updates (Examples)

- DSL Forum issues Technical Reports (TRs)
- TR-046 "Auto-Configuration: Architecture & Framework"
- TR-059 “Support of QoS-Enabled IP Services”
- TR-066 “ADSL Network Element Mgmt”
- TR-067 “ADSL Interoperability Test Plan”

Reference: www.DSLFORUM.org
CPE Modem/Router Examples

- Siemens SpeedStream 5600 SOHO Router ADSL2+
- Comtrend CT-536Plus 802.11g Wireless ADSL2+
- Thomson Speedtouch ST620 ADSL2+/ADSL2/RE

CPE DSL Gateway

- Residential Gateway
- Provides …
  - Sharing of a high speed DSL line
  - LAN interface (Ethernet hub, USB, HomePNA)
  - Optional wireless support IEEE 802.11b, HomeRF, HomePlug
  - HomePNA (Home Phoneline Networking Alliance)
  - HomePlug (HomePlug Powerline Alliance)
  - Optional firewall protection
  - DHCP, NAT support

- Examples;
  - http://www.2wire.com
  - http://www.netopia.com/
DSL Central Office Equipment

OSP (Outside Plant) termination inside the CO

MDF

Splitter

OSP Switch

Optional

Cross Connect

DSLAM

Data Network

MDF (Main Distribution Frame)
2. Coax Cable

- Coax/CATV hybrid coax and fiber
- ITU-T J.122
- PacketCable
- DOCSIS
- CableHome

Cable Architecture
DOCSIS 2.0 Overview

- Symmetrical services are enabled by DOCSIS 2.0
  - 1.5x greater efficiency
    - operates at 64 QAM
  - 2x wider channels
    - new 6.4 MHz wide channel
- DOCSIS 2.0 widens the pipe for IP traffic, allowing cable providers to create more and better services for voice, video, and data
- It does this by using enhanced modulation and improved error correction
- Superior ingress and impulse noise performance

DOCSIS™ Road Map

<table>
<thead>
<tr>
<th>DOCSIS</th>
<th>Key Features</th>
<th>Benefits/Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOCSIS 2.0</td>
<td>- Mandatory S-CDMA/TDMA</td>
<td>- Symmetric services</td>
</tr>
<tr>
<td>(30 Mbps u/s)</td>
<td>- Best of DOCSIS</td>
<td>- Peer-to-peer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Business-to-business (20 T1 capacity)</td>
</tr>
<tr>
<td>DOCSIS 1.1</td>
<td>- QoS</td>
<td>- Tiered service</td>
</tr>
<tr>
<td>(10 Mbps u/s)</td>
<td>- Pre-EQ</td>
<td>- Double u/s capacity</td>
</tr>
<tr>
<td></td>
<td>- Operations</td>
<td>- Lower op’s costs</td>
</tr>
<tr>
<td></td>
<td>- Security</td>
<td>- Better than competitor</td>
</tr>
<tr>
<td>DOCSIS 1.0</td>
<td>- Spec’d for retail</td>
<td>- High speed data</td>
</tr>
<tr>
<td>(5 Mbps u/s)</td>
<td>- Standard spec</td>
<td>- Internet access</td>
</tr>
</tbody>
</table>
3. PLC (Power Line Carrier)

- Power Line Telecommunication (PLT)
- Broadband over Power Line (BPL)
- ITU Radiocommunication Sector (ITU-R) Sub Working Group (SWG) 6E1 concerned about interference with radio broadcasters
- Low data rate PLC systems utilize frequencies in the range 9 kHz and 525 kHz
- BPL uses carrier frequencies in the range 2 - 30 MHz
Copper Access Summary

1. DSL
   Based on the 1 billion copper access loops
   64.1 Million installed by Jan 2004
   ADSL2+ at 24 Mbps standardized by ITU-T G.992.5
   ADSL2++ proposed at 52 Mbps

2. Coax/CATV
   36.8 Million installed by Jan 2004
   ITU-T J.122

3. PLC
   ITU-R in discussion