Course 8-9
DSL (Digital Subscriber Line) access techniques.

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Content of the course

- Principles of DSL access;
- SDSL techniques;
  - Classification;
  - The HDSL technique;
  - The CAP/QAM modulation.
- ADSL techniques;
  - Classification/Characteristics;
  - ADSL frequency band allocation;
  - Access architecture/Connection to line;
  - Distortions which affects the ADSL transmissions;
  - The principles of DMT modulation/DMT performances.
- VDSL techniques;
  - VDSL frequency band allocation;
  - Categories of VDSL techniques;
  - Performances of the VDSL techniques.
Conținutul cursului

- ADSL2 techniques;
  - Characteristics/Features;
  - Power management and rate adaptation;
  - The CVoDSL techniques;
  - Additional benefits.
- ADSL2+ techniques;
  - Allocation of the ADSL2+ frequency bands;
  - ADSL2+ / ADSL2 performances.
- VDSL2 techniques;
  - Characteristics/Features;
  - Allocation of the VDSL2 frequency bands;
  - VDSL2 performances.
The principles of DSL

- The term refers to the technologies and equipments used in a telephone network to ensure the access to a high speed digital network on a twisted wire line;

- There are two basic categories, namely:
  - SDSL – Symmetric DSL;
  - ADSL – Asymmetric DSL;

- SDSL ensures the same transfer rate in both directions:
  - upstream → subscriber – exchange;
  - downstream → exchange – subscriber;
    - due to the attenuation and crosstalk these systems can work only at medium frequencies;
    - the symmetric DSL variants include: SDSL, SHDSL, MSDSL, HDSL, HDSL-2, IDSL;
    - SDSL is ideal for LAN, bidirectional-video, web servers.
The principles of DSL

- ADSL ensures:
  - In downstream a large bandwidth channel;
    - situated at high frequencies;
  - In upstream a more narrow bandwidth channel;
    - situated at low frequencies;

- This division of the frequency bands has two reasons:
  - The information quantity transmitted in „downstream” is larger;
  - It is reduced the near end crosstalk at the user;
    - which is higher at high frequencies.

- ADSL variants include:
  - ADSL;
  - ADSL G.lite;
    - ensures smaller transfer rates but the connection to the line is simpler;
  - RADSL (Rate adaptive ADSL);
  - VDSL;
    - can work both in symmetric and asymmetric mode.
The principles of DSL

Characteristics of various xDSL techniques:

<table>
<thead>
<tr>
<th>DSL variant</th>
<th>Symmetric / Asymmetric</th>
<th>Bit rate</th>
<th>Telephone service</th>
<th>Number of pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Downstream</td>
<td>Upstream</td>
<td></td>
</tr>
<tr>
<td>ADSL</td>
<td>Asymmetric</td>
<td>1.5 Mbps up to 6.1 Mbps</td>
<td>64 kbps up to 640kbps</td>
<td>Yes</td>
</tr>
<tr>
<td>G.lite ADSL</td>
<td>Asymmetric</td>
<td>Up to 1.5Mbps</td>
<td>Up to 500kbps</td>
<td>Yes</td>
</tr>
<tr>
<td>HDSL</td>
<td>Symmetric</td>
<td>1.5 Mbps</td>
<td>1.5 Mbps</td>
<td>No</td>
</tr>
<tr>
<td>HDSL2</td>
<td>Symmetric</td>
<td>1.5 Mbps</td>
<td>1.5 Mbps</td>
<td>No</td>
</tr>
<tr>
<td>IDSL</td>
<td>Symmetric</td>
<td>144 kbps</td>
<td>144 kbps</td>
<td>No</td>
</tr>
<tr>
<td>MSDSL</td>
<td>Symmetric</td>
<td>1.5 Mbps</td>
<td>1.5 Mbps</td>
<td>No</td>
</tr>
<tr>
<td>RADSL</td>
<td>Both</td>
<td>1 Mbps up to 7 Mbps</td>
<td>128 kbps up to 1 Mbps</td>
<td>Yes</td>
</tr>
<tr>
<td>SDSL</td>
<td>Symmetric</td>
<td>2.3 Mbps</td>
<td>2.3 Mbps</td>
<td>No</td>
</tr>
<tr>
<td>SHDSL</td>
<td>Symmetric</td>
<td>2.3 Mbps</td>
<td>2.3 Mbps</td>
<td>No</td>
</tr>
<tr>
<td>VDSL</td>
<td>Asymmetric</td>
<td>Up to 52 Mbps</td>
<td>Over 1.5 Mbps</td>
<td>Yes</td>
</tr>
</tbody>
</table>

- characteristic downstream and upstream bit rates;
- number of pairs used;
- compatibility with the standard telephone service.
The principles of DSL

- Average transmission distance ensured by different xDSL techniques;
SDSL techniques

- **HDSL (High data rate Digital Subscriber Line)**;
  - Older version of symmetric DSL created as an alternative to the T1 and E1 services;
  - Transmits a rate of 1,544Mbps on two pairs of twisted wire;
    - on each pair a 784kbps rate is transmitted in full-duplex mode
    - it uses the echo compensation technique.
  - Allows the use of normal lines (0.5 mm – no preconditioning) with a 12000ft (3700m) maximum length without the use of repeaters;
    - does not allows the standard telephone service on these lines.

- **HDSL2 (Second generation HDSL)**;
  - Ensures a rate of 1,5Mbps in both directions on a single pair of twisted wire;
    - does not allows the standard telephone service on these lines.
SDSL techniques

- IDSL (Integrated Services Digital Network DSL);
  - Ensures symmetrical rates up to 144kbps using existing telephone lines and ISDN terminal (ISDN modem);
  - Differs from the ISDN by the fact that it is continuously available;
    - it is used for WAN (Wide Area Network) type applications;
    - does not allow the standard telephone service;

- SDSL (Symmetric Digital Subscriber Line);
  - Ensures high transfer rates on a single twisted pair for T1 and E1 applications;
    - the maximum transfer rate is 2,32Mbps;
    - allows Ethernet interface between the SDSL modem and the user equipment.
SDSL techniques

- **SHDSL (Symmetric High bit rate Digital Subscriber Line)**;
  - Allows a 20% higher coverage than SDSL;
  - Allows the use of one or two pairs of twisted wire;
    - for ex. 1,2Mbps transfer rate can be transmitted at 20000ft (6100m) on two normal (0.4 mm) pairs.

- **MSDSL ("Multi-rate Symmetric Digital Subscriber Line")**;
  - Allows the adaptive change of the rate according to the type of the line;
    - for ex. using the CAP modulation (Carrierless Amplitude & Phase Modulation) are available 8 discrete rates between 64kbps/128kbps (29000ft – 8900m – 0,5mm) and 2Mbps (15000ft – 4600m).
The HDSL technique

- The basic schematic of a HDSL connection;

- Connection to the line and power supply of the remote HDSL terminal;

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Telephony
The HDSL technique

- Comparison between the HDSL and T1 transmission modes;

![Diagram showing HDSL and T1 transceivers](image)

- HDSL transceiver: 1,544 Mbps, 392 kbaud/s, 784 kbps
- T-1 transceiver: 1,544 Mbps

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The HDSL technique

- Comparison between the HDSL and T1 transmission modes:
  - T1 technique:
    - lines must be preconditioned;
    - line repeater are required;
    - simplex transmission on each pair of wire;
    - line code: AMI or B8ZS;
    - sensitive to line swapping and polarity reversal.
  - HDSL technique:
    - no preconditioned lines are required;
      - allows bridge taps and wire gauge changes;
    - no repeaters are necessary for distances < 12000ft;
    - duplex transmission on each pair of wire;
    - line code: 2B1Q;
    - transparent to line swapping and polarity reversal.
The CAP modulation

- The QAM modulation is one of the best options for data transmissions;
- It allows the use in the same frequency band of two orthogonal sine carriers:
  - a sine carrier and a cosine carrier;
  - on each carrier are transmitted different signals in the same bandwidth.

\[ s_{QAM}(t) = (I(t) * h_{LPF(t)}) \cdot \cos(\omega_c t) + (Q(t) * h_{LPF(t)}) \cdot \sin(\omega_c t) = I'(t) \cdot \cos(\omega_c t) + Q'(t) \cdot \sin(\omega_c t) \]

- \( h_{LPF(t)} \) is the impulse response of low pass shaping filters.

- Block schematic of a QAM modulator:
The CAP modulation

- Block schematic of a QAM demodulator:

- The $I''(t)$ and $Q''(t)$ signals obtained after the QAM demodulation using a local carrier with $f_c + \Delta f_c$ frequency and phase $\phi$:

$$I''(t) = (s_{\text{QAM}}(t) \cdot \cos(\omega_c t + \Delta \omega_c t + \phi)) \ast h_{\text{LPF}}(t) = \left( (I'(t) \cdot \cos(\omega_c t) + Q'(t) \cdot \sin(\omega_c t)) \cdot \cos(\omega_c t + \Delta \omega_c t + \phi) \right) \ast h_{\text{LPF}}(t) =$$

$$= \left[ \frac{I'(t)}{2} \cdot \left[ \cos(2\omega_c t + \Delta \omega_c t + \phi) + \cos(\Delta \omega_c t + \phi) \right] + \frac{Q'(t)}{2} \cdot \left[ \sin(2\omega_c t + \Delta \omega_c t + \phi) - \sin(\Delta \omega_c t + \phi) \right] \right] \ast h_{\text{LPF}}(t) =$$

$$= \left[ \frac{I'(t)}{2} \cdot \cos(\Delta \omega_c t + \phi) - \frac{Q'(t)}{2} \cdot \sin(\Delta \omega_c t + \phi) \right] \ast h_{\text{LPF}}(t)$$
The CAP modulation

\[ Q''(t) = \left( s_{QAM}(t) \cdot \sin(\omega_c t + \Delta \omega_c t + \phi) \right) * h_{LPF}(t) = \left( (I'(t) \cdot \cos(\omega_c t) + Q'(t) \cdot \sin(\omega_c t)) \cdot \sin(\omega_c t + \Delta \omega_c t + \phi) \right) * h_{LPF}(t) = \]

\[ = \left[ \frac{I'(t)}{2} \cdot \sin(2\omega_c t + \Delta \omega_c t + \phi) + \sin(\Delta \omega_c t + \phi) \right] + \frac{Q'(t)}{2} \cdot \left[ \cos(\Delta \omega_c t + \phi) - \cos(2\omega_c t + \Delta \omega_c t + \phi) \right] * h_{LPF}(t) = \]

- If the carrier recovery is perfect, meaning \( \Delta \omega_c = 0 \) and \( \phi = 0 \), then \( I''(t) \) and \( Q''(t) \) demodulated signals are:
  \[
  I''(t) = I'(t) * h_{LPF}(t) \quad ; \quad Q''(t) = Q'(t) * h_{LPF}(t)
  \]

- The use of QAM type modulations in the subscriber loop implies the following issues:
  - the bandwidth of the QAM signal is twice of the \( I(t) \) and \( Q(t) \) modulator signals bandwidth;
  - the spectrum of the QAM signal is centered on the carrier frequency;
  - carrier recovery is necessary.

- The use of a base-band transmission with high spectral efficiency is the best idea.
The CAP modulation

- Spectrum of QAM modulated signal; BPF and LPF channel transfer characteristics;

\[|H_{\text{channel}}(f)| \ ; |S_{\text{QAM}}(f)|\]

- The channel characteristic is given by the transfer function of the twisted wires and of the separation transformers;

- It is difficult to “position” the QAM spectrum in an efficient way the pectrul QAM in the channel characteristic of the subscriber loop.

\[|H_{\text{subscriber-loop}}(f)|\]
The CAP modulation

- The CAP modulation ensures the transmission of two different baseband signals in the same frequency band;
- Block schematic of the CAP modulator:

\[
s_{\text{CAP}}(t) = I(t) * h_{\text{ef}}(t) + Q(t) * h_{\text{eq}}(t)
\]
The CAP modulation

- Conditions imposed to the transmission and reception filters transfer functions:
  \[ |H_{ef}(\omega)| = |H_{eq}(\omega)| \quad \forall \omega \]
  \[ \varphi_{ef}(\omega) = \varphi_{eq}(\omega) + \frac{\pi}{2} \quad \text{if } \omega > 0 \]; \[ \varphi_{ef}(\omega) = \varphi_{eq}(\omega) - \frac{\pi}{2} \quad \text{if } \omega < 0 \]
  \[ h_{ef}(t) * h_{eq}(t) = 0 \]
  \[ \varphi_{rf}(\omega) = \varphi_{eq}(\omega) + \frac{\pi}{2} \quad \text{if } \omega > 0 \]; \[ \varphi_{rf}(\omega) = \varphi_{eq}(\omega) - \frac{\pi}{2} \quad \text{if } \omega < 0 \]
  \[ \varphi_{rq}(\omega) = \varphi_{ef}(\omega) + \frac{\pi}{2} \quad \text{if } \omega > 0 \]; \[ \varphi_{rq}(\omega) = \varphi_{ef}(\omega) - \frac{\pi}{2} \quad \text{if } \omega < 0 \]

- The in-phase and quadrature filters are related by the Hilbert transform:
  - the quadrature filter transfer characteristic can be obtained from the in-phase filter by applying the Hilbert transform to the in-phase filter transfer characteristic.

- The bandwidth of the CAP modulated signals is half of the QAM modulated ones;

- The spectrum is centered at low frequencies where the subscriber loop attenuation is low.
The CAP modulation

- Block schematic of the CAP demodulator:

\[ I''(t) = s_{CAP}(t) * h_{rf}(t) = (I(t) * h_{ef}(t) + Q(t) * h_{eq}(t)) * h_{rf}(t) = I(t) * (h_{ef}(t) * h_{rf}(t)) + Q(t) * (h_{eq}(t) * h_{rf}(t)) = I(t) * (h_{ef}(t) * h_{rf}(t)) \]

\[ Q''(t) = s_{CAP}(t) * h_{rq}(t) = (I(t) * h_{ef}(t) + Q(t) * h_{eq}(t)) * h_{rq}(t) = I(t) * (h_{ef}(t) * h_{rq}(t)) + Q(t) * (h_{eq}(t) * h_{rq}(t)) = Q(t) * (h_{eq}(t) * h_{rq}(t)) \]
ADSL techniques

- ADSL (Asymmetric Digital Subscriber Line);
  - Can provide rates between 6 and 9 Mbps in downstream and up to 1Mbps in upstream;
  - Was developed in the late 1980s, its original function being video delivery over copper (twisted pairs);
  - Currently is used for high bit rate data transfer – high speed Internet access;
  - Works on a single pair of twisted wire and allows the standard telephone service;

- ADSL G.lite – is a simplified variant of ADSL for domestic users;
  - It can deliver in downstream up to 1,5Mbps and up to 500kbps in upstream;
    - the connection to the telephone line is simpler.
ADSL techniques

- **RADSL (Rate Adaptive Digital Subscriber Line);**
  - Allows the adaptation of the transmission rate up to 7Mbps in downstream and up to 1Mbps in upstream;
  - The transceiver adapts automatically the bandwidth assigned to upstream and downstream transmission in order to obtain the highest possible effective rate;
  - Allows both symmetrical and asymmetrical applications.

- **VDSL (Very high bit rate Digital Subscriber Line);**
  - Can deliver transfer rates between 25Mbps and 50Mbps can be obtained over low distances (ten meters, maximum hundred meters);
    - meaning between the user and the optical fiber;
  - It can be configured also for symmetric transmissions;
  - The first standardization activities have started in 1995;
  - Standardized in 2003: G.993.1 (VDSL1):
    - the main transmission technique is DMT, QAM being an alternative possibility.
### ADSL techniques

- **Main parameters of the ADSL and VDSL techniques:**

<table>
<thead>
<tr>
<th>xDSL</th>
<th>Maximum downstream bit rate</th>
<th>Maximum upstream bit rate</th>
<th>Maximum transmission range</th>
<th>Number of pairs/Connection to line</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADSL</td>
<td>8 Mbps</td>
<td>1,544 Mbps</td>
<td>5.5 km</td>
<td>1 pair; with splitter</td>
</tr>
<tr>
<td>ADSL G.Lite</td>
<td>1,5 Mbps</td>
<td>512 kbps</td>
<td>5.5 km</td>
<td>1 pair; no splitter</td>
</tr>
<tr>
<td>RADSL</td>
<td>8 Mbps</td>
<td>1,544 Mbps</td>
<td>5.5 km</td>
<td>1 pair; with splitter</td>
</tr>
<tr>
<td>VDSL</td>
<td>13 Mbps</td>
<td>1,6 Mbps</td>
<td>1.5 km</td>
<td>1 pair; with splitter</td>
</tr>
<tr>
<td></td>
<td>26 Mbps</td>
<td>3,2 Mbps</td>
<td>900 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>52 Mbps</td>
<td>6,4 Mbps</td>
<td>300 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>34 Mbps</td>
<td>34 Mbps</td>
<td>300 m</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Subscriber loop length (km)</th>
<th>Typical ADSL transfer rates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>„upstream`</td>
</tr>
<tr>
<td>5.5</td>
<td>64 kbps</td>
</tr>
<tr>
<td>4.88</td>
<td>65 kbps</td>
</tr>
<tr>
<td>3.66</td>
<td>256 kbps</td>
</tr>
<tr>
<td>2.8</td>
<td>640 kbps</td>
</tr>
</tbody>
</table>
ADSL network access

- ADSL access scenarios;

![Diagram of ADSL network access](image)

- **ADSL**
- **FTTNode**
- **FTTNode**
- **FTTHome**
- **FTTBuilding**

- Local exchange
- Concentrator
- Distribution point
- Subscriber
- Optical fiber
- Copper

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*Telephony*
Allocation of ADSL frequency bands

- ADSL frequency band allocation;
  - Depends on the duplexing technique employed:
    - separation of the upstream and downstream transmissions by using frequency multiplexing;
      - is the most used duplexing method;
      - it provides a smaller downstream bit rate, but simplifies the duplexing and equalization.

- the figure indicates also the filtering characteristics and the transmission and reception signal levels.

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Telephony
**Allocation of ADSL frequency bands**

- separation of the upstream and downstream transmissions by using the echo compensation technique;
  - allows larger downstream bit rates, but the duplexing and equalization become more complex;
  - this duplexing method is less used.

- the figure indicates also the filtering characteristics and the transmission and reception signal levels.
ADSL line connection

- ADSL access architecture;

- Connection to the line of the ADSL modem and of the phone device when the splitter is used.
ADSL line connection

- ADSL modem line interface when transmission direction separation is performed by using frequency multiplexing;

![Diagram of ADSL line connection](image.png)

- Digital DSP components:
  - Converters, analog filters, and amplifiers

- External passive filter with high dynamic range

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Telephony
ADSL line connection

- ADSL modem line interface when transmission direction separation is performed by using the echo compensation technique;

- Digital DSP components

- D/A converters, analog filters and amplifiers

- Filt.
ADSL distortions

- The main distortions affecting the ADSL transmissions:
  - The frequency transfer characteristic of the twisted wires from the subscriber loop:
    - attenuation (loss);
      - increases with the length of the cable and the frequency;
    - attenuation distortion;
      - changes with the frequency.
  
- Ex.: frequency transfer characteristic of a cable:
ADSL distortions

- Reflected signals generated by impedance mismatches;
  - affect the frequency transfer characteristic;
    - generate spectral zeros at some frequencies;
  - unterminated bridge taps: represent a major cause for impedance mismatches.
  - ex.: typical architecture of a subscriber loop;

- Noise:
  - background noise: thermal noise, shot noise;
  - crosstalk: near-end and far-end crosstalk;
  - radio interferences;
  - impulse noise.

- Nonlinear distortions.
The DMT modulation

- The principle of DMT modulation:
  - The DMT modulation is a multicarrier modulation;
    - it splits the allocated frequency band into a number $N$ (usually large) of sub-channels;
    - each sub-channel has a complex harmonic sub-carrier ($e^{j\omega t} = \cos(\omega t) + j\sin(\omega t)$);
      - the sub-carriers allocated to different sub-channels are orthogonal;
      - the orthogonality of the sub-carrier allows the separation of the sub-channel at the reception without filtering;
        - it is possible a spectral overlapping of the neighbor sub-channels and the provisioning of high spectral efficiency.
  - the DMT modulation is equivalent with a group of parallel QAM modulations;
    - can be used a separate modulation constellation on each individual sub-channel;
    - the filters having the impulse response $g(t)$, used to filter the complex data impulses $X_i(t)$, could be avoided in most of the situations;
      - the modulator impulses are not filtered before modulation.

- The orthogonality condition imposed to the complex sub-carriers:
  - $f_s$: bandwidth of a sub-channel;
  - $k$: sub-channel number;
  
  \[
  \frac{1}{T_s} \int_0^{T_s} e^{j\omega_s t} \cdot e^{-j\omega_s t} dt = \begin{cases} 
  0 & \text{if } m \neq n \\
  1 & \text{if } m = n
  \end{cases}
  \]
The DMT modulation

- The principle of the DMT modulation:

\[ g(t) \]

\[ e^{j2\pi f_1 t} \]

\[ e^{j2\pi f_2 t} \]

\[ e^{j2\pi f_{N/2} t} \]

\[ X_1 \rightarrow g(t) \rightarrow \times \rightarrow e^{j2\pi f_1 t} \rightarrow \downarrow \rightarrow Q \]

\[ X_2 \rightarrow g(t) \rightarrow \times \rightarrow e^{j2\pi f_2 t} \rightarrow \downarrow \rightarrow \oplus \rightarrow I \]

\[ X_{N/2} \rightarrow g(t) \rightarrow \times \rightarrow e^{j2\pi f_{N/2} t} \rightarrow \downarrow \rightarrow \oplus \rightarrow \text{digital implementation} \]

\[ X_1 \rightarrow \oplus \rightarrow e^{j2\pi f_1 t} \rightarrow \downarrow \rightarrow Q \]

\[ X_2 \rightarrow \oplus \rightarrow e^{j2\pi f_2 t} \rightarrow \downarrow \rightarrow I \]

\[ X_{N/2} \rightarrow \oplus \rightarrow e^{j2\pi f_{N/2} t} \rightarrow \downarrow \rightarrow \text{digital implementation} \]
The DMT modulation

- Allocation of the ADSL sub-carriers:
  - Sub-carrier (tone) separation = 4,3125kHz= DMT symbol frequency;
  - There are used 255 sub-carriers; maximum no. bits/tone = 15.

- Frequency and tone allocation for ADSL transmissions using the DMT modulation frequency division duplexing:
  - 25 tones are allocated for upstream;
  - 215 tones are allocated for downstream;
  - there are guard tones between the ADSL bands and separately for the telephone band.
The DMT modulation

- Adaptation of DMT modulation to the channel frequency transfer characteristic and noises and interferences on the channel;
  - Possible due to the adaptation of modulation used in each sub-channel;
  - DMT has superior performance comparatively to CAP modulation;
  - The selective assignment of the number of bits/tone ensures an equalization of the channel;
  - It is possible to do a fine adaptation of the transmission rate to the channel distortions.

**Diagram:**

- **a)** bits/sub-carrier for an ideal (flat) channel.
- **b)** Line transfer characteristic + distortions with interference.
- **c)** bits/sub-carrier for a real channel.
The DMT modulation

- Comparison between the DMT and CAP modulations:
  - Rate adaptation capability to the channel characteristics;
  - The transmission distance ensured.
Allocation of the VDSL frequencies

- VDSL frequency allocation plans:
  - plan 998; frequency allocation plan: North America, Europe, Japan
    
    | MHz  |
    |------|
    | 2.5  |
    | 1.38 |
    | 3.75 |
    | 5.2  |
    | 8.5  |
    | 12.0 |
    
    band O is optional and can be used for either upstream or downstream transmission

  - plan 997; frequency allocation plan: Europe
    
    | MHz  |
    |------|
    | 2.5  |
    | 1.38 |
    | 3.0  |
    | 5.1  |
    | 7.05 |
    | 12.0 |

- The frequency band allocation for the upstream and the downstream directions is more complex than for the ADSL:
  - there are two frequency allocation plans:
    - one valid globally and one valid in Europe;
  - it is allocated a wide band for upstream at high frequencies (the 2US band);
    - at high frequencies the channel inserts significant attenuation distortions;
    - it is not possible the use of modulation constellations with a large number of bits/symbol.
Allocation of the VDSL frequencies

- it is allocated a narrower upstream band (1US) at lower frequencies;
  - it used when the transmission can not be realized (or does not worth to be realized), due to the low quality of the channel, in the 2US band.
- in downstream are allocated two approximately equal frequency bands (1DS and 2DS), having bandwidths of 2 – 3MHz;
  - these bands are allocated at lower frequencies, where the distortions inserted by the channel are reduced.
- can be noticed the intelligent allocation of these frequency bands:
  - a DS band at lower frequencies where can be obtained a high downstream bit rate;
  - a US band where can be provided a high upstream bit rate;
  - another DS band where can be obtained a smaller bit rate than the one obtained in the first DS band (due to the larger attenuation inserted by the channel);
  - a second US band usable in the case of cables with low length.

- The frequency band allocation allows symmetrical transmission modes:
  - the same bit rate in upstream and in downstream.
The VDSL spectral mask

- The VDSL spectral mask and the spectral compatibility of the xDSL techniques;

- The figure presents for comparison purposes the spectral density of the telephone and of the BA-ISDN signals;
VDSL techniques categories

- It is of interest the interaction between the ADSL and VDSL techniques:
  - if it is targeted the decrease of the crosstalk between the ADSL and VDSL transmissions:
    - the spectrum of the VDSL signals has to be inferiorly limited at 1.1Mhz;
    - has to be reduced the 1DS band;
    - could be also about the transmission on the same pair of the ADSL and VDSL signals;
    - ADSL compatible mode (called also “ADSL friendly” mode).
  - if the VDSL connection is established directly to the exchange (“Central Office based VDSL”), usually it is used the extended (entire) band;
    - VDSL efficient mode.
    - can be explained by the higher length of the subscriber – exchange connection cable relatively to the length of the subscriber – concentrator connection cable;
    - if the cable is longer the attenuation distortions induced by the line are larger and to provide appropriate bite rates has to be used also the ADSL frequency band.
  - if the VDSL connection is realized only to a concentrator (“Cabinet based VDSL”), usually it is used the reduced band;
  - usually we have the following situation:
    - “Cabinet based VDSL” works in ADSL compatible mode;
    - “Central Office based VDSL” works in VDSL efficient mode.
Case study:
- The maximum bit rates attainable in downstream and upstream according to the usage of the available frequency bands and the length of the subscriber loop;
- Downstream transmission;

<table>
<thead>
<tr>
<th>L (km)</th>
<th>D (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>40</td>
</tr>
<tr>
<td>0.45</td>
<td>35</td>
</tr>
<tr>
<td>0.6</td>
<td>30</td>
</tr>
<tr>
<td>0.75</td>
<td>25</td>
</tr>
<tr>
<td>0.925</td>
<td>20</td>
</tr>
<tr>
<td>1.075</td>
<td>15</td>
</tr>
<tr>
<td>1.225</td>
<td>10</td>
</tr>
<tr>
<td>1.375</td>
<td>5</td>
</tr>
</tbody>
</table>

Year 2014 – 2015
Semester II

Telephony
VDSL performances

- The maximum downstream bit rate varies between 20Mbps - 40Mbps for loops shorter than 300m and decreases below 5Mbps for loops having a length of 1.5km;
  - can be noticed the bit rate difference between ADSL compatible and respectively the ADSL incompatible techniques;
  - can be noticed also the supplementary bit rate provided by the 2DS band, but only for short subscriber loops.
- Upstream transmission;

![Upstream transmission diagram]

<table>
<thead>
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<th>D (Mbps)</th>
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</thead>
<tbody>
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<tr>
<td>0.75</td>
<td>0</td>
</tr>
<tr>
<td>0.925</td>
<td>only 1U</td>
</tr>
<tr>
<td>1.075</td>
<td>only 2U</td>
</tr>
<tr>
<td>1.225</td>
<td>VDSL efficient</td>
</tr>
</tbody>
</table>

Telephony
VDSL performances

- The maximum upstream bit rates are located between the following limits:
  - 5Mbps - 15Mbps for loops shorter than 300m;
  - the transmission in upstream is not possible for loops longer than 750m – 1200m;
  - can be noticed the impossibility of using the 2US band at loop lengths larger than 600m – 650m;
    - this is due to the significant distortions induced by the channel in this band.
  - the transmission in the 1US band is less affected by the increase of the subscriber loop length.
ADSL2 techniques

- Extra functionalities provided by the ADSL2 standard:
  - Higher transmission bit rate;
  - Larger coverage area;
  - More flexible adaptation of the transfer rate to the channel characteristics;
  - Channel diagnostic functionalitites;
    - can be measured:
      - the background noise;
      - the loop attenuation;
      - signal to noise ratio;
    - the diagnostic information are sent to the central office and are used for service quality monitoring.
  - Stand-by functioning mode;
ADSL2 provides the following performances:

- downstream bit rate up to 12Mbps;
- upstream bit rate and up to 1Mbps;
- these performances are obtained due to the following techniques:
  - the increase of the modulation efficiency;
  - the decrease of framing overhead;
  - larger coding gain:
  - more complex signal processing;
  - improved initialization.
ADSL2 techniques

- Improved power management methods:
  - ADSL modems operate continuously in the “full-power” mode;
    - L0 mode (even when nothing is transmitted);
      - significant consumption of energy which is a problem especially in the case of “cabinet based ADSL”: problems related to power supply and heat dissipation;
  - The ADSL2 techniques brings two new power management techniques, namely:
    - L2 “low-power mode”: dedicated to the ATU-C modem located in the CO (or cabinet);
      - it is allowed the fast entering and exiting of the low-power mode based on the data traffic on the connection;
        - if the traffic is large the modem works continuously in the full power mode (L0) to maximize the transmission speed;
        - in the moment when the traffic decreases the modem enters the L2 operation mode and a reduced bit rate is used to transmit;
        - the switching between the two functioning modes is realized instantaneously and without affecting the error probability or the service quality;
ADSL2 techniques

- L3 “low-power mode”: dedicated both to ATU-C and ATU-R modems;
  - the modem enters a “sleep mode” in the moment when no traffic is detected on the connection for a longer time interval;
  - transition to normal operation requires approximately 3s.
ADSL2 techniques

- Power management techniques used by the ADSL2 modems;
ADSL2 techniques

- Bonded ADSL (developed in 2005);
  - Is an important functionality of ADSL2;
  - Allows the increase of the bit rate by coupling several telephone lines in a single ADSL connection;
    - it is necessary the insertion of a multiplexing/demultiplexing layer which allows the distribution of a larger flow on different physical connections.
ADSL2 techniques

- ADSL2 offers the possibility to split the bandwidth in channels with different characteristics for different applications;
- ADSL2 offers support for voice applications in parallel with data transmissions;
  - higher allowed bit error probability but smaller delay for voice transmissions;
  - smaller allowed bit error probability but larger delay for data transmissions.
- this capacity for channelization provides support for CVoDSL – Channelized Voice over DSL;
  - transparent transmission method of TDM voice channels with DSL technique;
  - 64kbps bit rate channels are reserved for transmission of DS0 channels to CO or to a multiplexer;
  - have to be reserved channels both in downstream and in upstream.
**ADSL2 techniques**

- The principle of CVoDSL technique for transmission of TDM voice channels over DSL;

- Additional benefits offered by the ADSL2 technique:
  - Improved interoperability;
    - the improvements of initialization procedures offer a better interoperability of equipment with chips from different suppliers;
  - Fast initialization (startup);
    - the initialization time can be reduced from 10s (ADSL) to 3s (ADSL2);
ADSL2+ techniques

● All-digital mode;
  ● optional mode in which the standard telephone band is used for data transmissions – the bit rate can be increased with 256kbps;

● Support for packet based services;
  ● it is provisioned a special convergence level which allows packet based services (for ex. Ethernet) to be transported over ADSL2;

● ADSL2+ it is an extension of the ADSL2 standard;
  ● ADSL2 specifies a downstream band of 1.1MHz or 552kHz (ADSL G.lite.bis), and ADSL2+ specifies a band of 2.2MHz;
    ● significant increase of the downstream bit rate for lines shorter than approximately 5000 feet;
    ● the upstream bit rate is around 1Mbps, according to the transmission channel parameters (length of the line).
ADSL2+ techniques

- Frequency band allocation for the ADSL2 and ADSL2+ techniques;

- ADSL2+ can be used to decrease the crosstalk by appropriate allocation of the downstream bands;
  - The frequency band located between 1.1MHz and 2.2MHz can be used for “cabinet based DSL”;
    - the shorter line induces smaller distortions of the frequency characteristic;
  - The ADSL2 band can be used for “central office based DSL”;

![Diagram of frequency bands for ADSL2 and ADSL2+ techniques]
ADSL2+ techniques

- Decrease of the crosstalk by appropriate allocation of the ADSL2+ downstream frequency bands;
ADSL2+ techniques

- ADSL, ADSL2, and ADSL2+ downstream bit rates obtained in white noise condition for different length of the subscriber loop;
  - Cable 26awg (“American wire gauge”);
    - diameter 0.4mm;
  - White noise spectral density: -140dBm/Hz.
ADSL2+ techniques

- ADSL, ADSL2, and ADSL2+ downstream bit rates obtained in crosstalk condition for different length of the subscriber loop;
  - Cable 26awg (“American wire gauge”);
  - 12 identical interference sources;
    - 12 “Self cross-talk”;

![Graph showing ADSL, ADSL2, and ADSL2+ downstream bit rates vs. loop length](image)
VDSL2 techniques

- Is the newest and most advanced DSL technology;
- Was designed to support a wide category of services;
  - voice, video, data, high definition TV (HDTV), interactive gaming.
- It is specified by the ITU-T G.993.2 standard and it is an enhancement of the G.993.1 (VDSL1) standard;
  - it is a complex standard with numerous profiles and frequency bands adapted to various bit rate and reach (coverage) requirements.
- It allows symmetrical and asymmetrical full duplex transmissions up to bit rates of 200Mbps on twisted pairs using a bandwidth of 30MHz;
- The VDSL2 standard includes many of the features and functionalities contained in the ADSL2+ standard;
  - Advanced functionalities:
    - advanced diagnostic, management, fault localization;
    - ability to maximize the bit rate and the efficiency of bandwidth use.
VDSL2 techniques

- VDSL2 uses completely different initialization procedures compared to the ones used by VDSL1;
  - Advanced channel measurement and modem training techniques;
    - the VDSL2 system allows the use of the US0 frequency band (used by ADSL systems) on long channels.

- VDSL2 ensures support for services based on packet transmissions (for ex. Ethernet or IP);
  - Evolved management facilities allow the transmission on the same physical layer of packets with different priorities and lengths;
  - VDSL2 provides also support for transmission on the same physical channel of services with completely different requirements:
    - bit error probability, delay, protection against impulse noise.

- VDSL2 ensures also:
  - Compatibility of equipment with different chip-set and compatibility with ADSL and ADSL2 techniques.
Transmission profiles defined by VDSL2 techniques;

- These profiles are characterized by:
  - allocated bandwidth;
  - number of tones (subcarriers) used (especially in downstream);
  - tone separation;
  - transmission power;
  - transfer rate (especially in downstream).

<table>
<thead>
<tr>
<th>Profile Parameter</th>
<th>8a</th>
<th>8b</th>
<th>8c</th>
<th>8d</th>
<th>12a</th>
<th>12b</th>
<th>17a</th>
<th>30a</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bandwidth MHz</strong></td>
<td>8.5</td>
<td>8.5</td>
<td>8.5</td>
<td>8.5</td>
<td>12</td>
<td>12</td>
<td>17.7</td>
<td>30</td>
</tr>
<tr>
<td><strong>Tones DS</strong></td>
<td>1971</td>
<td>1971</td>
<td>1971</td>
<td>1971</td>
<td>2770</td>
<td>2770</td>
<td>4095</td>
<td>2098</td>
</tr>
<tr>
<td><strong>Tone separation kHz</strong></td>
<td>4.312</td>
<td>4.312</td>
<td>4.312</td>
<td>4.312</td>
<td>4.312</td>
<td>4.312</td>
<td>4.312</td>
<td>8.625</td>
</tr>
<tr>
<td><strong>TX power DS dBm</strong></td>
<td>17.5</td>
<td>20.5</td>
<td>11.5</td>
<td>14.5</td>
<td>14.5</td>
<td>14.5</td>
<td>14.5</td>
<td>14.5</td>
</tr>
<tr>
<td><strong>Minimum net bit rate Mbps</strong></td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>68</td>
<td>68</td>
<td>100</td>
<td>200</td>
</tr>
</tbody>
</table>
**VDSL2 profiles**

- Frequency band allocation plans for VDSL2 techniques;

<table>
<thead>
<tr>
<th>Frequency Band Allocation Plan</th>
<th>Europe 3DS 0US</th>
<th>0.138</th>
<th>0.276</th>
<th>3.75</th>
<th>5.2</th>
<th>8.5</th>
<th>12</th>
<th>23</th>
<th>30 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan 998B (Annex B); Europe</td>
<td>0US</td>
<td>1DS</td>
<td>1US</td>
<td>2DS</td>
<td>2US</td>
<td>3DS</td>
<td>3US</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plan 998 extension; North America</td>
<td>1DS</td>
<td>1US</td>
<td>2DS</td>
<td>2US</td>
<td>3DS</td>
<td>3US</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
VDSL2 performances

- The VDSL2 system provides an improved protection against impulse noise;
  - The impulse noise is one of the most important distortions which affect DSL transmissions;
  - The VDSL2 system allows the correction of error packets generated by impulses with period between 250µs and 3,75ms;

- VDSL2 allows a large transmission distance similar with ADSL, meaning 1 – 4 Mbps at distances of 4 - 5 km;
  - In this case the transmission is similar with that of ADSL2;
  - The VDSL2 systems, contrary to VDSL1 systems, are not limited to short subscriber loops;
    - the VDSL1 have a typical reach of 3kft;
    - some of the ADSL characteristics are integrated in the VDSL2 systems (typical reach of 9kft).
The maximum VDSL2 bit rate at source is 250 Mbps;
- the bit rate deteriorates quickly to 100 Mbps at 0.5 km and to 50 Mbps at 1 km;
- at a distance of 1.6 km the maximum bit rate degrades slowly;
  - the performances are identical with those of ADSL2 systems.

![Graph showing VDSL2 performances]