USING SIMULATIONS FOR EVALUATION OF MEASUREMENTS ON ADSL2+ LINES

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SUMMARY

The ADSL2+ lines are gradually replacing the first generation of ADSL in homes and small offices connecting to the Internet. Since there is a need to estimate the transmission speed, we have used MATLAB Web Server to design a simulator of xDSL lines that is available at our web pages. This paper compares simulations with measurement results and proposes a methodology for evaluation of measurements based on the suggestions from Slovak Telecom in connection with the practical introduction of ADSL2+ technology in 2006.

The original analogue telephone lines use xDSL digital systems to a lesser or greater extent. Let us focus on the trend in the metallic access networks field and the potential possibilities for further development. Apart from the evolution of ADSL (Asymmetric Digital Subscriber Line) standards the transfer methods for the very high speed VDSL (Very-high-speed Digital Subscriber Line) are being optimized. An ADSL line transmits digital signals at various transfer speeds in opposing directions of transfer. For the connection of larger companies, especially those, which operate their own application and web servers, ADSL connection is not suitable although the SHDSL (Single-pair High-bit-rate Digital Subscriber Line) connection can be used.

Allocation of bands for transfer directions downstream and upstream and also the total width of the band is dependent on the ADSL variant given by the ITU-T standard. According to the recommendation of the ITU-T G.992.1 today's systems use a frequency band of up to 1.104 MHz. The lower part of the spectrum is of course used for telephone channels and for this reason it counts on the coexistence of ADSL in one conduit with the original analogue telephone connection (ADSL/POTS), which is preserved thanks to separation filters (adapter, splitter). Apart from this, ADSL can also coexist with the basic ISDN-BA connection (ADSL/ISDN).

Keywords: *access network, xDSL, ADSL, subscriber line, Matlab, simulation*

1. INDRODUCTION

Today, metallic lines are commonly used for the frequencies up to several MHz (ADSL – Asymmetric Digital Subscribe Line – up to 1.104 MHz, ADSL2+ up to 2.208 MHz) or even tens of MHz (VDSL – Very-high-speed Digital Subscribe Line). Technical calculations and simulations of processes in various areas of technology often use the MATLAB environment.

We have a good experience with using MATLAB Web Server for calculations and simulations of subscriber lines; it allows us publish the programs, e.g. for estimation of SHDSL. ADSL or VDSL transmission speed or for calculations of other parameters – see [2], [3].

Apart from the standards mentioned, a standard for second generation ADSL has also already been approved (ADSL2) ITU-T G.992.3, G.992.4. There are several paths leading to an increase in transfer speed compared to the present state. Firstly, it is possible to maximally use the reserves of existing ADSL connections.

Another possibility for increasing the maximum available transfer speed of the connection is to double the extent of the frequency band, meaning to 2.208 MHz. This is the path taken by ADSL2+ (ITU-T G.992.5), which is able to compete with VDSL connections for asymmetrical application with a level of transfer speed of 25 Mbps.

New version VDSL2 (Very-High-Bit-Rate Digital Subscriber Line 2) – ITU-T G.993.2, is the newest and most advanced standard of xDSL broadband wireline communications. It has been designed to support the wide deployment of Triple Play services such as voice, video, data, high definition television (HDTV) and interactive gaming. It allows symmetric transfer with data rates of up to 100 Mbps over short distances and ADSL-like long reach performance.

Transfer speed on ADSL and also on VDSL lines depends on many factors. On the one hand, the provider sets configuration of transfer speed for the subscriber according to the nature of the services provided and the user profile.

On the other hand though, there is a physical restriction stemming from the properties of the transfer environment, where the most applicable is the inhibition seen in conduit, growing with the frequency and then the cross-talk disturbance from other systems mounted onto multi-pair cables.

2. PROPERTIES OF THE TRANSMISSION ENVIRONMENT

The subscriber lines in access networks begin at the main distribution frame in local exchange, then they run as a part of multi-pair cables to line distribution frames, from which they are divided into smaller groups of subscriber lines or to individual lines leading to the subscribers' premises. In this distribution network there are used various types of cables with copper core (mostly 0.4 mm in diameter) and various number of pairs, basically arranged in quads. The principal factors limiting the transmission of high-speed signals are attenuation of the line and crosstalk between the individual pairs.

Typical relations between frequency and relative attenuation for lines with quad arrangement and various core attenuations are shown in Figure 1 for frequencies up to 2 MHz.

The article [4] describes some approaches to modeling; the model proposed by the British Telecom has been used also in the discussed program for xDSL simulation that can plot the attenuation characteristics of a line composed of various cables including taps.

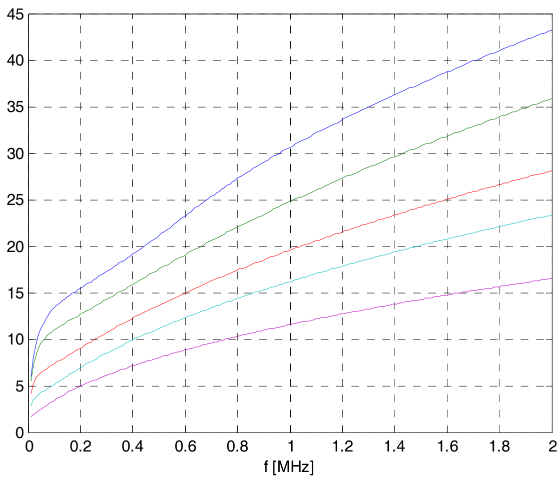

Fig. 1 Typical relations between frequency and relative attenuation for lines with quad arrangement (local telecommunication cables) – core diameters from upside: 0.32, 0.4, 0.5, 0.63 and 0.9 mm

The article [4] is dedicated to the influence of crosstalk between the pairs of conductors in telecommunication cables. It should be mentioned that the evaluation of information throughput for the pairs disturbed by different systems using different link codes must be based on power spectral density (PSD) of those systems, taking into account their superposition. The total noise originating from J various types of systems that are present in numbers n_1 to n_J is expressed in W/Hz and calculated from the following formula:

$$N(f)=N_{AWGN}+\left[\sum_{i=1}^{J}\left(n_i^{0,6}\cdot K_{NEXT}\cdot f^{1,5}\cdot S_{Ti}(f)\right)^{\frac{1}{0,6}}\right]^{0,6}+ \\ +\left[\sum_{i=1}^{J}\left(n_i^{0,6}\cdot K_{FEXT}\cdot f^{2}\cdot d\cdot S_{Ti}(f)\left|H(f,d)\right|^{2}\right)^{\frac{1}{0,6}}\right]^{0,6} \qquad (1)$$

N_{AWGN} white Gaussian noise in the background

$S_T(f)$ power spectral density of the signal at the output of the transmitter

$|H(f)|^2$ power transmission function for the respective line

K_{NEXT} near-end crosstalk parameter (NEXT) depending on the specific type of cable

K_{FEXT} far-end crosstalk parameter (FEXT) depending on the specific type of cable

d length of the line

The described method for summarizing of contributive crosstalks NEXT and FEXT is recommended by the FSAN (Full Service Access Network) consortium.

3. PROGRAM FOR ESTIMATION OF TRANSMISSION SPEED AND OTHER PARAMETERS

The described program, which is available at “http://matlab.feld.cvut.cz”, accepts many input parameters for the calculation and provides results in various forms.

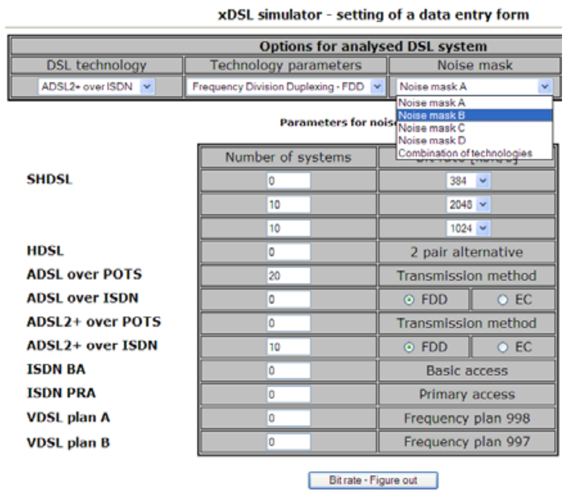

Fig. 2 Input screen of a program for estimation of xDSL transmission speed, offering basic options and requiring input of disturbing lines combination

First of all, the analyzed line is selected and the maximum achievable transmission speed is determined for it. The present configuration allows input of the following lines:

- SHDSL (ITU-T Recommendation G.991.2)
- ADSL over ISDN (ITU-T Recommendation G.992.1 Annex B)
- ADSL over POTS (ITU-T Recommendation G.992.1 Annex A)
- ADSL2+ over ISDN (ITU-T Recommendation G.992.5 Annex B)
- ADSL2+ over POTS (ITU-T Recommendation G.992.5 Annex A)
- VDSL over ISDN (ITU-T Recommendation G.993.1)

There is another option available for the individual lines. For ADSL/2+, the method of duplex transmission must be chosen – frequency division (FDD) or echo cancellation (EC). VDSL always uses FDD, but there is a question of frequency plan: A – suitable for asymmetric transmission, or B – suitable for symmetric transmission.

Noise profile – a standardized profile of crosstalk noise for testing of modems:
- A (cable highly used by digital systems – high noise level)
- B (medium-used cable)
- C (medium-used cable like B + PCM and ISDN-PRA systems using HDB3 code)
- D (just noise from same-type lines)
- Combination of different technologies

In the case of noise coming through a combination of technologies, the composition and numbers of lines operated simultaneously in the same cable are put in:
- SHDSL (three groups of lines with different transmission speeds may be defined)
- HDSL (two-pair alternative is taken into account)
- ADSL / 2+ over POTS, ADSL / 2+ over ISDN (also the duplex transmission method is chosen – FDD or EC)
- ISDN BA – basic line using 2B1Q code
- ISDN PRA – primary line (2048 kbit/s) using HDB3 code (or another line system – E1, PCM30/32)
- VDSL – plan A or B

It is also possible to define the noise margin. Usual value is 6 dB. The value of 0 dB is a boundary one and it should ensure the transmission error rate below 10^{-7}. For the separate calculation of noise and line parameters it is necessary to provide the following parameters: frequency step, upper frequency limit, noise direction. When transmission speed is calculated, the appropriate parameters are chosen automatically.

4. PARAMETERS FOR CALCULATION OF LINES AND THEIR DETERMINATION

The simulation program allows input of up to 10 line sections of different types and lengths, which may be defined either as regular line sections or as bridged taps. Cable type is characterized mainly by core diameter [mm]. The following types are offered:
- Typical European cables according to ETSI specified in the ITU-T Recommendation G.996.1, with core diameter 0.32 (ETSI), 0.4 (ETSI), 0.5 (ETSI), 0.63 (ETSI) or 0.9 (ETSI).
- Typical local quad cable TCEPKPFLE produced by Pražské kabelovny, with core diameter 0.4 (Prakab), 0.6 (Prakab) or 0.8 (Prakab).
- Typical local quad cable TCEPKPFLE according to Czech Telecom specifications – 0.4 (CT), 0.6 (CT) or 0.8 (CT).
- Indoor cables SXKFY – 0.5 (PE insulation), SYKFY – 0.5 (PVC insulation), UCEKFY – 0.4 (PE insulation), UTP cat 5 – 0.5 (LAN cable for frequencies up to 100 MHz).

If none of the listed line models is acceptable, it is possible to use the frequency characteristics with the most similar shape, adjusting its length as follows:

$$d^{l} = d \cdot \frac{A\left(f_{ref}\right)}{A^{l}\left(f_{ref}\right)} \qquad \text{[km; km, dB, dB]} \qquad (2)$$

- d actual length of the section
- $A(f_{ref})$ actual attenuation of the section at reference frequency
- $A'(f_{ref})$ attenuation of the used line model with length l at reference frequency

Under normal circumstances, the crosstalk parameters corresponding to the selected type of line are used for calculations. The introduction of user selection of crosstalk appears to be useful in practical application. It is necessary to provide values (obtained e.g. through measurement) for the worst case in the cable (most often crosstalk between pairs of conductors within a quad):
- Near-end crosstalk attenuation for the reference frequency ANEXT(fref) in [dB]
- Far-end crosstalk attenuation for the reference frequency AFEXT(fref) for the length d in [dB]
- Line attenuation for the reference frequency A(fref) in [dB] for length d
- Reference frequency fref in [kHz]
- Line length d in [km]

We can recommend that the NEXT crosstalk attenuation should be measured in a wider frequency band and the output graph should be complemented with a 15 dB/decade line in logarithmic frequency scale. The parameters used in crosstalk models – see formula (1) – can be expressed as follows:

$$K_{NEXT} = \frac{10^{-\frac{A_{NEXT}(f_{ref})}{10}}}{\sqrt{f_{ref}^{\ 3}}} \qquad (3)$$

$$K_{FEXT} = \frac{10^{\frac{A(f_{ref})-A_{FEXT}(f_{ref})}{10}}}{f_{ref}^{\ 2} \cdot d} \qquad (4)$$

The near-end crosstalk attenuation can be easily measured as both transmitter and receiver are on the same end of the line. For the unit length of the line we can use the following formula for the mutual relation between the crosstalk parameters near and far end:

$$K_{NEXT} = \frac{K_{FEXT}}{4 \cdot k_{\alpha}} \qquad (5)$$

where k_{α} is a parameter from the square-root attenuation model expressed for relative attenuation in Np/m (converted from dB/km through dividing by $8{,}86.10^{3}$).

Hence, the far-end crosstalk attenuation can be estimated using the formula:

$$A_{FEXT}\left(f_{ref}\right)=18+A_{NEXT}\left(f_{ref}\right)+A\left(f_{ref}\right)-$$
$$-10\cdot\log A\left(f_{ref}\right)-5\cdot\log f_{ref} \quad (6)$$

$A_{NEXT}(f_{ref})$	near-end crosstalk attenuation for the reference frequency in [dB]
$A_{FEXT}(f_{ref})$	far-end crosstalk attenuation for the reference frequency for the length d in [dB]
$A(f_{ref})$	line attenuation for the reference frequency in [dB] for length d
f_{ref}	reference frequency in [kHz]
d	line length in [km]

5. SIMULATION OUTPUTS AND A PROPOSAL OF MEASUREMENT PROCESSING

The most important simulation result is the estimated transmission speed for upstream and especially for downstream direction. Taking into account the results of measurement for a local cable TCEPKPFLE 75x4x0.4 mm equipped with mini IP DSLAM ZyXEL IES-1000 including AAM1212 module we have refined the code gains in the calculation program so that the results correspond to real operation.

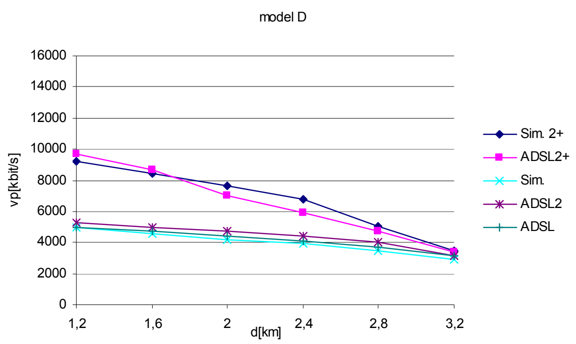

Fig. 3 Comparison of simulation results with measured speeds

Figure 3 compares the measured values with simulation results for injected crosstalk noise corresponding to the noise model D.

The line marked "Sim." represents the result of simulation that does not discriminate between generations (ADSL/2) as both alternatives use the same bandwidth; more substantial differences consist in the frame structure. The maximum achievable speeds are not very different, only for short lines with low noise we can reach more than 8 Mbit/s with ADSL2 (this case is not included in the graphs).

According to the requirements from Slovak Telecom we have proposed a methodology for extrapolation of transmission speed values, based on measurements in a network without ADSL2+ lines, using a simulation program available at our MATLAB Web Server, with subsequent processing through a common spreadsheet processor. The target value is 30% occupation of a cable with ADSL2+ lines.

The proposed procedure follows:

1. Obtaining simulation results from MATLAB Web Server for 0.4 mm lines and typical crosstalk
2. Interpolation of the values with a power set – see Figure 4
3. The resulting power set will be used as a formula for calculation of transmission speed, taking into account the length of the respective line
   a. If the difference of measurement results from simulation of a single ADSL2+ line is about +/-10%, the expected speed for 30% occupation will correspond to the function interpolated with simulation for 16 ADSL2+ lines in a cable
   b. If the difference of measurement results from simulation of a single ADSL2+ line is less than about -10%, there already more digital systems present in the cable or the cable is defective (and it should be tested)
   c. If the difference of measurement results from simulation of a single ADSL2+ line is more than about +10%, there is probably a large core diameter used in some section. In that case the cable composition should be checked and the simulation parameters refined.

In the case b. it is advisable to measure the noise PSD at the subscriber line. After finishing the prepared program supplement it will be possible to upload the measured values to the program at MATLAB Web Server.

The noise values will then be added to crosstalk, replacing N_{AWGN} in formula (1), and thus we will get the estimated speed reflecting the existing noise as well as the presumed growth of ADSL2+ lines in the cable up to the mentioned 30%.

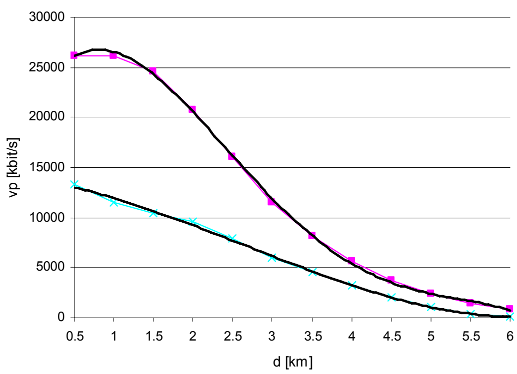

Fig. 4 An example of interleaved simulations for easy calculation in a spreadsheet processor

6. CONCLUSION

The ADSL2+ lines are gradually replacing the first generation of ADSL in homes and small offices connecting to the Internet. Since there is a need to estimate the transmission speed, we have used MATLAB Web Server to design a simulator of xDSL lines that is available at our web pages.

The described program, which is available at "http://matlab.feld.cvut.cz", accepts many input parameters for the calculation and provides results in various forms. The most important simulation result is the estimated transmission speed for upstream and especially for downstream direction.

Will be compared simulations with measurement results and proposes a methodology for evaluation of measurements based on the suggestions from Slovak Telecom in connection with the practical introduction of ADSL2+ technology in 2006.

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BIOGRAPHY

Ing. Jiří Vodrážka, Ph.D. – born in Prague in 1966. Since 1996 he has been working as an assistant lecturer at the Department of Telecommunication Engineering. He is the member of the state final examination commission for Telecommunication engineering. Since 2003 appointed supervisor of doctoral students, currently supervising 6 students. Giving lectures and leading exercises for the courses Transmission systems I and II. He regularly publishes papers concerning the mentioned areas at international conferences, member of editorial board of the Teleinformatika Conference in Prague. Member of the University Development Fund G1 grant committee and of a design team that prepares the Network plans at APVTS.

Ing. Jaromír Hrad, Ph.D. – born in Přerov in 1971. Since 1996 he has been working as an assistant lecturer at the Department of Telecommunication Engineering of the Faculty of Electrical Engineering, Czech Technical University in Prague. He is involved in activities related to data transmission and multimedia technologies and teaches the corresponding subjects. He regularly publishes papers concerning the mentioned areas at international conferences. From 1996 he has been a member of EAEEIE (European Association for Education in Electrical and Information Engineering).