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Simulation of Asymmetric Digital Subscriber Line

Impact of line characteristics on system performances

The growing demand to transmit high-speed digital data down copper pairs has resulted in a wide variety of transmission systems that have to co-exist on the same or adjacent binder groups. Asymetric digital subscriber line (ADSL) is a technology that can be used to convert the copper cable access line into a high-speed digital link and avoid overloading the circuit-switched public-switched telephone network (PSTN). This paper addresses the problem of maintaining spectrum compatibility between ADSL and other services that may use different transmission technologies.

Introduction

ADSL is a technology that allows broadband access from residences or small offices to the local exchange. It has the potential to supply residential and small business users with all types of new broadband services, from educational to financial, and customers would essentially need only a new ADSL modem, allowing up to 8 Mbit/s downstream (to the end user) and up to 1 Mbit/s upstream.

The American National Standards Institute (ANSI) T1E1.4 Standards Committee has selected the discrete multitone (DMT) as the standard modulation scheme for asymmetric DSL[1].

A multitone modulation scheme, such as DMT, has the flexibility to optimise the transmission capacity and the power spectrum over more than one (disjoint) frequency band.

The results presented here are for the specific application of DMT to carry ADSL payloads of over 8 Mbit/s from the network to the customer. Spectral compatibility between ADSL, high bit-rate DSL (HDSL), and integrated services digital network (ISDN) basic-rate access (BRA) systems are considered in two different Italian network scenarios—urban and rural areas.

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ADSL System

Figure 1 shows the ADSL network model. ADSL shares the existing telephone line with the plain old telephony system (POTS); at each end there is a set of filters that split the line by frequency: a low-pass filter passing telephone signals and a high-pass filter passing ADSL signals above 25 kHz. The high bit rate digital signals do not overload the existing telephone network because they are connected to a broadband network; that is, an asynchronous transfer mode (ATM) network.

Figure 2 shows the ADSL spectrum allocation. ADSL systems are planned to have two different spectrum allocations: frequency division multiplexing (FDM) between upstream and downstream, and echo cancellation with frequency overlapping.

ADSL Simulated System

Using DMT, the channel bandwidth is divided into N independent subcarriers, of bandwidth W, and n_i bits are assigned to each positive frequency sub-channel.

In the encoder, each set of n_i bits is mapped into a complex subsymbol, which forms the quadrature amplitude modulation (QAM) constellation for that subchannel. An N-point fast

Figure1—ADSL network diagram

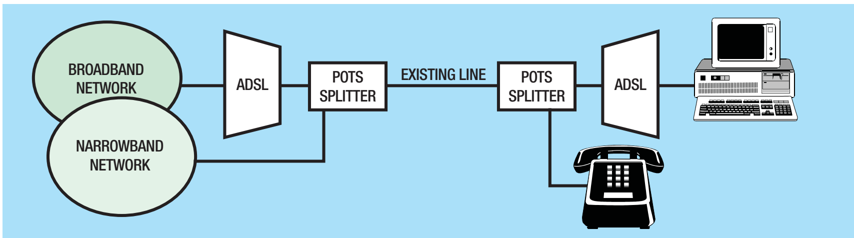
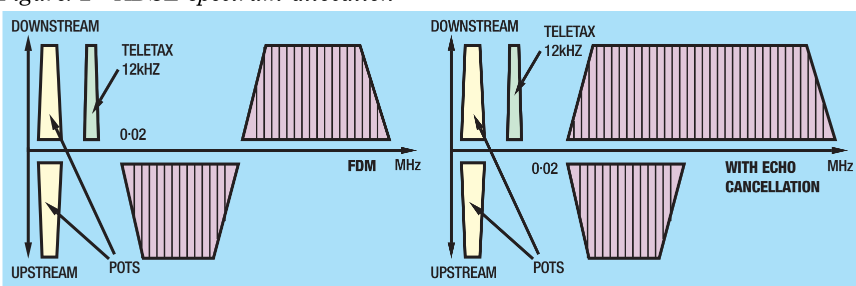


Figure. 2—ADSL spectrum allocation



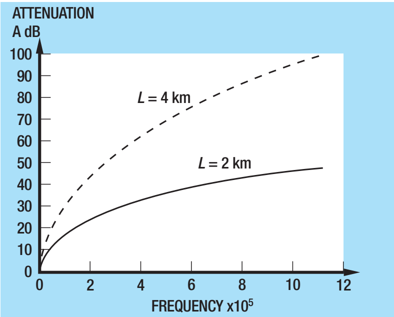


Figure 3—Cable attenuation versus frequency

Fourier transform is used to obtain the modulated signal. As the sub-channels are not independent for finite N, a cyclic prefix is used to remove the intersymbol interference (ISI) between the sub-channels[2,5].

The overall bit rate R_b is given by

$$R_b = \sum_{i=1}^{N} n_i W$$

The power of each QAM signal tone is equal to P_i and the total transmitted power is:

$$P = \sum_{i=1}^{N} P_i$$

The multitone modulation allows R_b to be maximised through an optimal choice of power and bits per symbol for each tone, under the restriction that the symbol error probabilities for all tones be equal and the total transmitted power P be limited[5]. The ANSI T1E1.4 standards committee selected the discrete multitone modulation for the implementation of asymmetric DSL, with the following parameters:

- W = 4 kHz;
- maximum n_i = 14 bits;
- maximum transmitted power spectral density (PSD) = –40 dBm/Hz;
- gain margin > 6 dB; and
- error probability $P_e < 10^{-7}$.

An FEC Reed Solomon Code is also applied before the modulation in order to reach a higher signal-to-noise ratio (SNR) at the receiver side[1].

The ANSIT1E1.413 specifics have been implemented in an ADSL simulation tool[3] and typical Italian network parameters have been considered for the urban and rural scenarios.

Scenarios

Two different scenarios have been considered here: urban areas, with an average copper loop length (L)=1000 m and rural areas, with an average copper loop length (L)=2000 m; in both cases a copper wire diameter of 0·4 mm has been considered. The cable length assumed for the implementation is twice the average value in both environments, because in the Italian network more than 90% of cables length is below 2 × (L). The copper pairs attenuation is plotted in Figure 3 for both the urban and rural cases, showing the proportional dependence on the square root of the frequency and the cable length:

$$A_{dB} = \alpha\sqrt{f} \times L$$

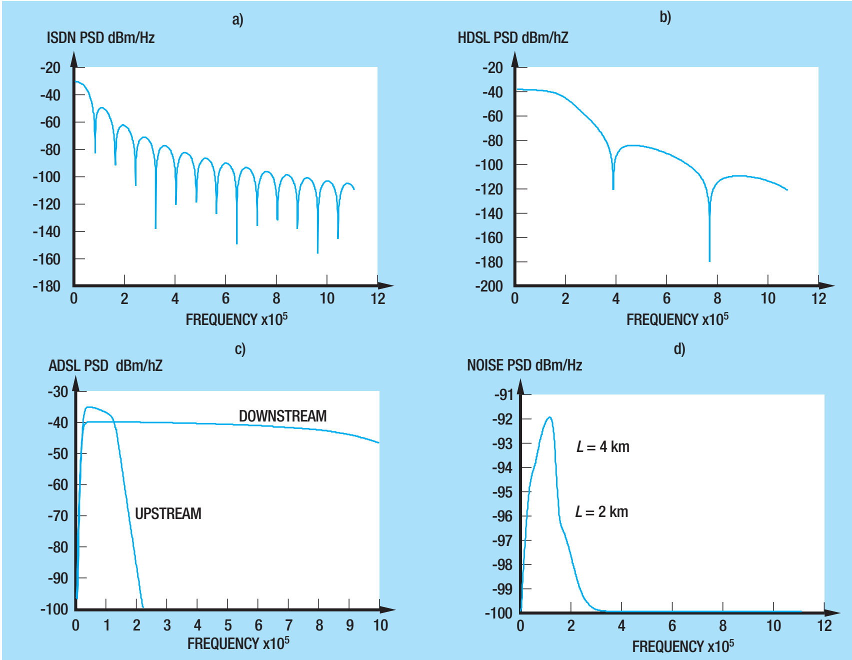


Figure 4—Power spectral densities of: (a) ISDN BRA; (b) HDSL; (c) ADSL upstream and downstream; (d) NEXT+FEXT+ additive white Gaussian noise (AWGN)

Interference Model

Models of near-end and far-end cross talk (NEXT and FEXT) interference due to others transmission systems that have to co-exist in the same or adjacent binder groups have been developed in the ANSI T1E1.4 Working Group and have been taken into account for the simulation[4].

The following power spectral densities for NEXT and FEXT noise have been considered:

$$\text{NEXT}(f) = \left((S_1(f)X_N f^{3/2} n_1^{0\cdot6})^{1/0\cdot6} + \ldots + (S_I(f)X_N f^{3/2} n_I^{0\cdot6})^{1/0\cdot6}\right)^{0\cdot6}$$

$$\text{FEXT}(f) = \left((S_1(f)H^2(f)X_F f^2 n_1^{0\cdot6})^{1/0\cdot6} + \ldots + (S_I(f)H^2(f)X_F f^2 n_I^{0\cdot6})^{1/0\cdot6}\right)^{0\cdot6}$$

where $S_i(f)$ is the PSD of the i^{th} interfering system, n_i the number of i^{th} type interfering transmission systems, $H(f)$ the channel frequency response and I the number of different interfering systems. The frequency is in MHz.

The crosstalk attenuation X can be approximated with a Gaussian random variable, but constant values have been put in the model, meaning that the 90% of X realisations fall under the chosen value.

Figures 4(a), 4(b) and 4(c) show the PSDs of ISDN, HDSL, and ADSL upstream (taken into account in NEXT) and ADSL downstream (taken into account in NEXT) and ADSL downstream (taken into account in FEXT).

Simulation Results

The crosstalk configuration for both urban and rural cases has been chosen for 30 ISDN, 5 HDSL and 30 ADSL and an additive white Gaussian noise floor equal to –100 dBm/Hz has been considered.

Table 1 shows the downstream gross and net achievable data rates with an ADSL system with echo cancellation (lower band edge of 26 kHz). The net data rate is obtained removing the overhead channel bit rate, the cyclic prefix overhead and the FEC redundancy.

Figures 4(d), 5 and 6 show, respectively, the total noise PSD (meaning NEXT+FEXT+AWGN), the measured SNR at the receiver end, and the bit allocation in frequency for both urban and rural cases.

Figure 4(*d*) shows the total noise contribution for the two scenarios. It can be seen that there are no differences between the urban and rural cases because the FEXT noise contribution is negligible at the ADSL frequencies. Figure 5 shows the received SNR; in the rural case SNR is lower because of the higher cable length; the bit allocation directly reflects the SNR behaviour (Figure 6).

The depicted case shows that in urban areas more than 90% of copper pairs allow the installation of an ADSL system with a net bit rate reaching more than 8 Mbit/s (Table 1).

In rural areas, because of the longer cable length, a lower bit rate can be reached, depending on interference and cable characteristics. With the interference configuration chosen in this study, more than 90% of copper pairs in rural areas permit, with an ADSL system, up to 4Mbit/s. Those results apply when considering only the copper pairs between the central office and the subscriber locations.

Figure 5—SNR at the receiver end side

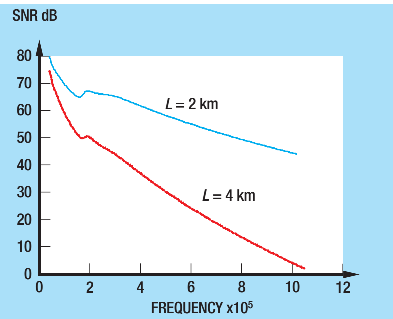
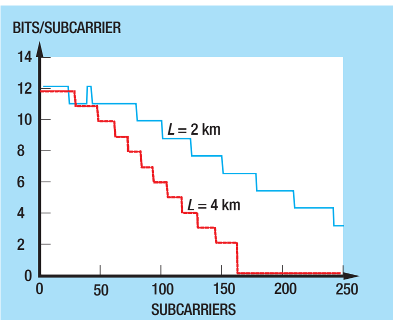


Figure 6—Bit allocation for urban and rural case



A typical loop is usually terminated by some additional wiring at the central office and subscriber locations. These additional wires can have lengths that can vary from a few metres to several hundreds, and they tend to have worse performances than the twisted pairs used in the loop plant. Moreover, some of the access network twisted pairs are bridged tapped, and the signals reflected from bridged taps cause an echo noise that, taken into account in the channel model, lowers the ADSL capacity. Between the NEXT and FEXT interference, HDB3 is incompatible with ADSL because it makes the system bit rate fall down; ISDN has a worse impact on ADSL upstream than downstream; not too many HDSL systems have been put into the ADSL cable because of their influence on system performances.

Conclusions

This paper presented the results of a study to determine how ADSL technology can meet the growing demand for multimedia services in two typical scenarios: urban and rural areas. It has been shown how cable characteristics and interference impact on ADSL performances, considering the twisted pairs used in the loop plant and typical interference.

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Table 1: Bit rates in the two cases

	Gross Bit Rate	Net Bit Rate
Urban case	> 8Mbit/s	~ 8 Mbit/s
Rural case	< 4·8 Mbit/s	< 4·1 Mbit/s

Biographies

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Gaetano Vespasiano was born in Catignano, Italy, in 1959. He received his degree in Electrical Engineering from the University of L'Aquila in 1984. In 1986 he joined the Scuola Superiore 'G. Reiss Romoli' where he teaches on optical fibre communication systems and broadband access networks. He has been active in the field of optical communications for 12 years and has published many papers and two books. Current research programmes include: WDM transmission for an all optical network, high-speed data transmission using copper pairs, comparison of alternatives for the broadband access network.

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Maria Stella Iacobucci was born in L'Aquila, Italy, in 1972. She received the Dr. Ing. Degree in Electrical Engineering from the University of L'Aquila, Italy, in 1995. After graduation she was engaged in research on communication theory and coding from the Infocom department of the University of Rome 'La Sapienza'. Since 1997 she has been with SSGRR (Scuola Superiore Guglielmo Reiss Romoli), the post graduate school in telecommunications of the Telecom Italia holding group in L'Aquila. Her current research interests include digital communication theory and coding, performance evaluations, spread spectrum systems.