Simulation of ADSL over ISDN on German Subscriber Lines

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***Abstract*—The shortcomings of the existing asymmetric digital subscriber line (ADSL) standard ANSI T1.413 for the application with Integrated Services Digital Network (ISDN) are explained. An ADSL system modified by increasing the high-pass cutoff frequency of the splitter to about 140 kHz and, therefore, moving also the pilots has been simulated under the noise conditions and ISDN requirements of the German subscriber-line network. The reach reduction due to ISDN compared with the "plain old telephone service" (POTS) application is shown to be between 10% and 15%. It is proposed to apply ISDN ADSL rather than POTS ADSL.**

I. Introduction

The ASYMMETRIC digital subscriber line (ADSL) is a technique, that provides high bit rate services such as fast internet access or video-on-demand to customer premises over subscriber lines. Additionally, a low bit rate duplex channel is available. The ADSL standard T1.413 of the American National Standards Institute (ANSI) favors the discrete multitone (DMT) modulation. DMT is a flexible transmission method, which can easily adapt for a desired data rate, taking into account the signal-to-noise ratio (SNR) of a given channel. The frequency range of up to 1.104 MHz is divided into 256 (sub-)carriers and a QAM alphabet is assigned to each carrier, where the QAM size of each carrier is chosen according to its SNR value.

The main advantage of ADSL is that the customer can still use the "plain old telephone service" (POTS) together with high bit rate services over only a single loop (twisted pair). This is achieved by a POTS splitter, which separates the POTS-related and the ADSL signal.

II. Demand for ISDN-Compatible ADSL

Especially inside Germany, an increasing number of customers (currently about 2 million) has an Integrated Services Digital Network basic rate access (ISDN BRA) instead of POTS and all subscriber loops will be connected to ISDN-capable digital central offices by the end of 1997. Unfortunately, ADSL systems according to the standard T1.413 are not fully compatible with ISDN, implying the need of two separate loops. Note that just the ISDN customers are potential internet and, hence, ADSL users.

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Transmitting the ISDN signal via the duplex bearer designated in the standard for this purpose is not possible in the German network, because the ISDN requirements:

1) latency $\leq$ 1.25 ms;
2) activation time $\leq$ 170 ms;
3) emergency power supply of one ISDN telephone in case of local power failure;

cannot be easily achieved. Furthermore, the existing ISDN equipment can no longer be used.

Thus, for the German telephone network, we propose the installation of ISDN-compatible ADSL systems rather than POTS ADSL. A positive side effect is the easier design of a universal ISDN splitter suitable to all countries because of the international ISDN recommendation ITU-T G.961 (even with the alternative between 2B1Q and MMS43 line codes, see below). In contrast to this, POTS splitters must vary from country to country due to different national requirements.

Such an ADSL system was simulated to evaluate the reduction of reach resulting from the inclusion of ISDN, relative to POTS. The transmission-channel parameters (loop attenuation and disturbance) were chosen according to the characteristics of the German subscriber-line network.

III. Noise Environment

For ADSL systems within the German subscriber-line network, three major existing and planned near-end crosstalk (NEXT) sources that use a frequency band of up to 1.1 MHz must be considered:

1) AslMx (German abbreviation for subscriber line multiplexer);
2) primary rate access (PRA);
3) high-rate digital subscriber line (HDSL).

The AslMx specified in Germany carries 26 POTS or 13 ISDN BRA channels on two loops in simplex mode. The modulation method is either 2B1Q (4-PAM, symbol rate 1024 kbaud) or DMT (64 carriers, spacing 6.281 kHz). The second principal disturber is a PRA system with a rate of 2048 kb/s which is HDB3 coded. HDSL exists in some variants, where the data are transmitted on one, two, or three loops in duplex mode (net data rate of 2048 kb/s). The modulation method is 2B1Q. From measurements we know that the AslMx is a critical disturber for 2-Mb/s ADSL.

Two NEXT frequency responses are important, the worse one between two loops within a star quad (= 2 loops) of a basic bundle (five star quads), and the one between two loops of adjacent star quads (see [1]).

TABLE I
OMITTED CARRIERS DEPENDING ON THE EDGE FREQUENCY f_e OF THE ADSL SIGNAL ($\hat{=}$ CUTOFF FREQUENCY OF HIGH-PASS FILTER)

f_e/kHz	type of access	omitted carriers
25	POTS	1-5, 16, 64
80	ISDN	1–19, 32, 64
100	ISDN	1–24, 32, 64
120	ISDN	1–28, 32 64
140	ISDN	1–33, 64, 128
150	ISDN	1–35, 64, 128

IV. CHOSEN SYSTEM PARAMETERS

For the simulation of the loop and the noise environment, we used four-fold oversampling compared with the DMT sampling rate. The simulations were restricted to AslMx (2B1Q) disturbers assuming the worst case. Two different numbers of AslMx systems were considered (1 and 8). In the case of one AslMx system, the disturber was located in the same star quad with the ADSL system. Otherwise, the disturbers were operating in adjacent star quads. AWGN with a noise power spectral density of −120 dBm/Hz was also added.

For POTS ADSL, we used an almost standard compliant 2.048-Mb/s system (255 carriers, spacing 4.3125 kHz). Only the downstream channels were simulated, whereas the upstream channel was assumed to be separated by an ideal echo canceler. Carriers 1 to 5, 16, and 64 were omitted for POTS transmission and pilots.

For ADSL over ISDN, the POTS–ADSL system was modified omitting more carriers. Additionally, at least one pilot frequency has to be changed, because it is located within the ISDN band. The omitted carriers (see Table I) depend on the required 3-dB cutoff frequency of the high-pass filter of the ISDN splitter, which is chosen to be the edge frequency f_e of the ADSL signal. Preliminary measurements of ISDN BRA with splitters showed that a 40-dB cutoff frequency of about 110 kHz of a Chebyshev-type low-pass filter of order nine (central office and customer filter, together) was necessary for the MMS43 line code used in Germany (MMS43 bandwidth = 120 kHz). The 2B1Q line code used in most of the other countries has a bandwidth of only 80 kHz and will require a lower edge frequency of the ADSL signal (see, suggestion in Section V).

Further parameters: Reed–Solomon code (146, 134) with interleaver depth 32, no trellis coding, guard interval = 32 samples, maximum number of bits allocated per carrier = 11, maximum allowed transmit power = 100 mW, reference impedance = 100 Ω, roll-off factor of transmit and receive filters = 0.55, wire diameter = 0.4 mm (AWG 26), bit allocation algorithm = [2], time-domain equalizer is based on a patent application which is currently being prepared.

V. SIMULATION RESULTS

The reach was defined as the length of the loop connected to the ADSL system in any noise environment at a bit error ratio (BER) of 10^{-7} after decoding. During the simulation, no margin was considered, because only the differences in reach, i.e., the reduction of reach due to ISDN, were important for this analysis.

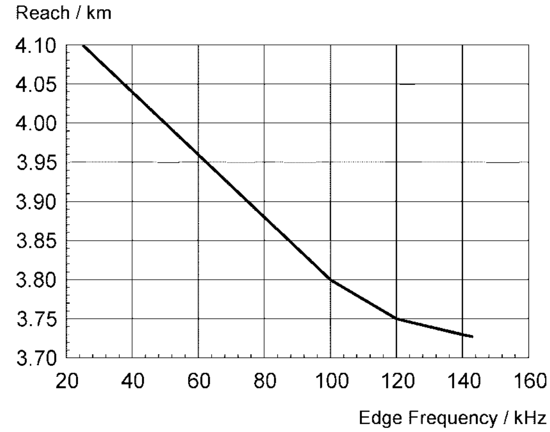

Fig. 1. Reach of the 2.048-Mb/s ADSL system dependent on the edge frequency f_e of the ADSL signal (0.4-mm wire, 1 AslMx).

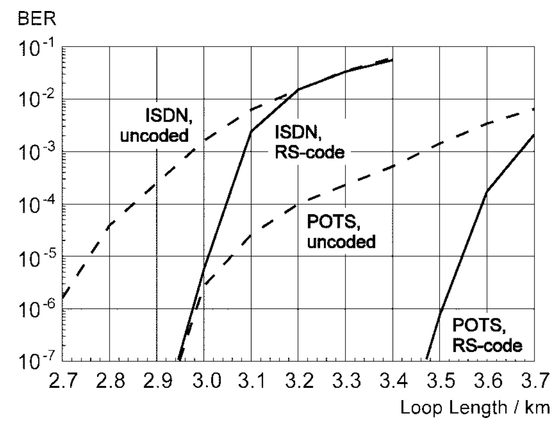

Fig. 2. Bit error ratio (BER) of uncoded and coded ADSL over POTS or ISDN (140 kHz), 2.048 Mb/s, 0.4-mm wire, 8 AslMx.

The dependence of the reach on the edge frequency f_e is depicted in Fig. 1. The omitted carriers were chosen according to Table I. The reach of POTS ADSL ($f_e = 25$ kHz) was 4.1 km with one AslMx disturber and 0.4-mm wires. ISDN ADSL achieved loop lengths between 3.73 and 3.88 km. The curve is almost linear between 25 and 100 kHz with a slope of −40 m/10 kHz. The reduction of reach between 100 and 120 kHz is 50 m, and between 120 and 140 kHz is only 20 m.

The difference in ADSL reach between 2B1Q and MMS43 ISDN line codes is only about 70 m (reach difference between 100 and 140 kHz), which can be neglected. Therefore, ISDN splitters for MMS43 could be applied for both 2B1Q and MMS43 ISDN. In the sequel, an edge frequency of 140 kHz is assumed.

Fig. 2 shows BER curves dependent on the loop length for uncoded and coded ADSL over POTS or ISDN with eight AslMx disturbers as the worst case. The ADSL system achieved a loop length of 3.47 km for POTS and a length of 2.95 km for ISDN. In this example, ISDN reduced the reach by about 500 m. Under the given conditions, the reach reduction of ADSL over ISDN compared with POTS ADSL is assumed to lie between 10% and 15%.

VI. CONCLUSIONS

ADSL according to the ANSI standard T1.413 cannot be used for ADSL over ISDN. An ISDN-compatible ADSL system omitting the carriers of the ISDN band (33 carriers $\hat{=}$140 kHz) and moving the pilots out of band was simulated in order to evaluate the reach. ISDN compared with POTS reduced the reach by 10%–15%, i.e., 400–500 m for 0.4-mm loops. With one AslMx disturber, the ISDN–ADSL system reached 3.73 km.

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