DIGITAL SUBSCRIBER LINE TECHNOLOGY: NETWORK ARCHITECTURE, DEPLOYMENT PROBLEMS AND TECHNICAL SOLUTIONS

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I INTRODUCTION

One of the most talked-about areas in the telecommunications industry today is digital subscriber line (DSL) technology. DSL may be offered as ISDN DSL (IDSL), high-bit-rate DSL (HDSL), symmetric DSL (SDSL), asymmetric DSL (ADSL) or very high speed DSL (VDSL). This group of technologies is frequently referred to as “xDSL”.

This paper discusses essential characteristics of xDSL technologies and their application. The first part of the paper supplies a brief overview of all types of xDSL technologies, emphasizing modulation techniques, access network architecture and deployment problems. Technical aspects of xDSL deployment in the unbundling process are also presented. The second part of the paper is dedicated to description of a HDSL modem developed in Mihajlo Pupin Institute, focussing on modem design and implementation of operation and management (O&M) system. Development of this modem represents an instructive example of possibilities to follow leading manufacturers and to accelerate xDSL deployment in our country.

II THE COPPER PAIR: A TECHNOLOGICAL BENEFIT AND A TECHNICAL CHALLENGE

For a long time copper pairs were exclusively used for voice transmission, that is, for the Plain Old Telephone Service (POTS). Digitalization of telecommunication systems marked the new era in treating and using the subscriber network. Digital systems enabled providing of new telecommunication services to end users. Simultaneous transmission of voice, data and management information has been achieved, by applying E1 and T1 transmission systems. A serious limit in faster deployment of these services towards the end users was the lack of appropriate transmission systems for broadband signals. The main problem with T1 lines was the distance limit, which required repeaters in the network in order to cover the full carrier service area loops.

Deployment of fiber optic networks has been foreseen as a possible solution to overcome the problem. Unfortunately, initial expectations that fiber optic should extend to the end users until the end of the 20th century were too optimistic, even for the most developed countries. Economical reasons and urgent requirements for the new services directed the efforts towards inventing new technologies that could offer broadband services over the existing infrastructure. These efforts resulted in the attempt to resolve the problem by means of high performance transceivers that should extend the distance limit, thus eliminating the need for repeaters and achieve transmission characteristics that could make the transmission robust to degradations and disturbances in a wire line environment.

This approach has been verified by developing of the original DSL in the early 1980s, which provided high quality transmission capability for a single ISDN Basic Access customer over a non-loaded two-wire telephone loop [1]. Today, it is usually referred to as IDSL (ISDN DSL) to avoid confusion with the other DSL technologies. Types of xDSL services available and the associated ITU-T recommendations are presented in Table 1.

III HDSL/SDSL TECHNOLOGY

In 1988 ANSI formed a working group T1E1.4 which had a task to suggest DSL access on 1.544 Mb/s, in order to replace existing T1 lines. In 1989 Ameritech and Bellcore achieved first successful field trials with rates of 1.544Mb/s. The transmission system was called *High bit rate Digital Subscriber Line* - HDSL. An important part of the undertaken investigations in the HDSL scope had been loop plants characteristics of few large cities in USA. The overview of these works can be found in [2], [3].

HDSL environment

A brief survey of the most important twisted pair transmission characteristics and local plant impairments is presented in few following paragraphs. Propagation loss and linear distortion (amplitude, phase and delay) are well understood impairments for the twisted-pair channel. They depend on physical parameters such as loop length and wire diameter, mismatch of impedance, frequency, etc. The amplitude distortion and loss are dominantly dependent on frequency. The loss function is approximately proportional to $f^{1/2}$ [3].

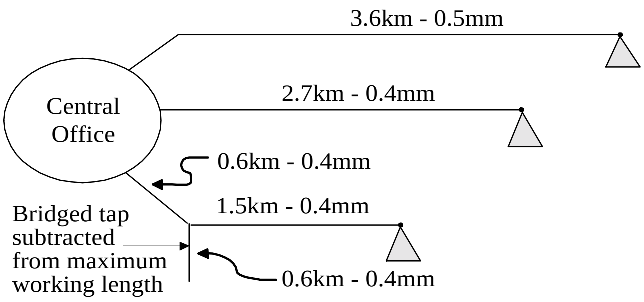

Figure 1. A carrier service area around a central office.

The surveys of the loop plant loss characteristics as well as the capabilities of modem transmission technologies suggested the concept of a carrier service area (CSA) [2]. The aim of introduction of CSA was to separate an appropriate plant segment of administration area suitable for HDSL systems as illustrated in Figure 1.

The near-end (NEXT) and far-end crosstalk (FEXT) are two types of crosstalk generated in a multi-pair cable. From a data communication point of view NEXT is generally more damaging than FEXT. This is because NEXT does not necessarily propagate through a long loop and thus does not experience the corresponding propagation loss. There are a many works addressed to the NEXT issues and a few well known models.

Table 1. Types of xDSL services available and the associated ITU-T recommendations [4], [5]

DSL type	Description	ITU-T Rec.	Data rate	Distance limit	Application
ADSL	Assymetric DSL	G.992.1 (ex G.dmt)	1.544-8.448 Mb/s downstream 32-768 kb/s upstream	1.544Mb/s at 5.5km 2.048Mb/s at 4.8km 6.312Mb/s at 3.6km 8.448Mb/s at 2.7km	Internet and Web access, video on demand, motion video, remote LAN access
ADSL Lite	Splitterless ADSL	G.992.2 (ex G.lite)	1.544-6 Mb/s downstream (depends on subscribed service)	5.5km on 0.5mm wire	Same as ADSL, without splitter at the user's home or business, at lower speed
HDSL	High Bit Rate DSL	G.991.1 (ex G.hdsl)	1.544 Mb/s duplex on two twisted-pair lines; 2.048 Mb/s duplex on three twisted-pair lines	3.6km on 0.5mm wire	Replacemnet for E1/T1 service, WAN, LAN, server access
IDSL	ISDN DSL	-	128kb/s	5.5km on 0.5mm wire	Similar to the ISDN service but data only (no voice on the same line)
SDSL	Symmetric DSL	G.shdsl (G.992.2)	1.544 Mb/s or 2.048Mb/s on a single duplex line downstream / upstream	3.6km on 0.5mm wire	Same as for HDSL but requiring only one line of a twisted pair cable
VDSL	Very High Bit Rate DSL	G.vdsl (G.993 series)	12.9-51.8Mb/s downstream, 1.5Mb/s to 2.3 Mb/s upstream	1.4km at 12.96Mb/s, 0.9km at 25.82 Mb/s, 0.3km at 51.84 Mb/s	ATM networks; fiber to the neighborhood (FTTx)

The one of them, proposed by Bellcore [3] is depicted in Figure 2. This model was obtained by computer simulations for a 0.65mm cable of length 5.5km with 50 pairs.

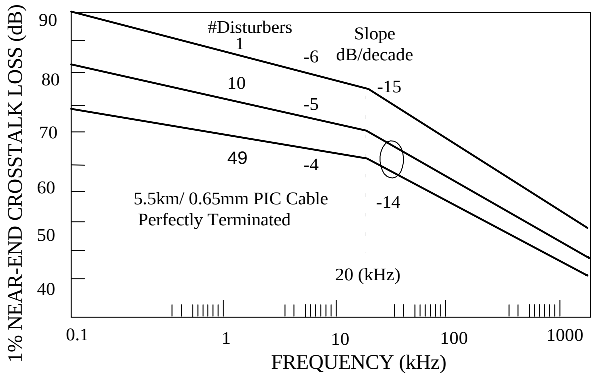

Figure 2. NEXT models for a 5.5km /0.65mm cable [3].

Another source of twisted-pair characteristic impairments are bridged tapes, which are intended to provide plant flexibility for future additions and changes in service demands. Figure 3. depicts two of the damaging effects introduced by a bridged tap. The reflected signal by opened circuited twisted pair (bridge), which is delayed and distorted version of the main signal, creates two types of interference. The first will appear as a noisy component to a remote receiver and the second will appear as an echo to the local transceiver.

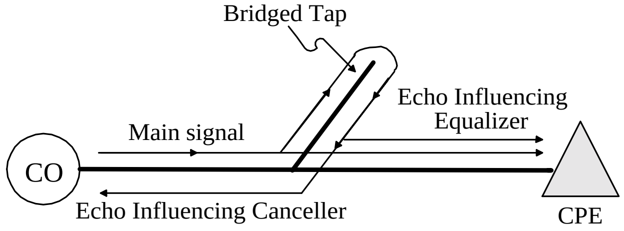

Figure 3. Echo generation in a bridged tap.

In unshielded twisted pairs, impulse noise can be generated by a variety of man-made equipment and environmental disturbances such as signaling circuits, transmission and switching gear, electrostatic discharges, lightning surges, etc. Surveys on impulse noise in the loop plant have indicated that, statistically, impulse noise has well-defined characteristics. The most significant of them are: occurrences about 1-5 times per minute, peak amplitudes in the 5-20 mV range, most of the energy concentrated below 40 kHz and time duration in the range 30-150 ms [2].

In addition to above shortly described impairments it is very important to mention another sources such as change of wire diameter, mismatched impedance, thermal noise, change of temperature and so forth.

Baseband and Passband Transmission Schemes

Two modulation schemes were contenders for HDSL, 2B1Q line code, which is four-level baseband pulse amplitude modulation (PAM), and passband quadrature modulation (QAM). The line code 2B1Q successfully used in ISDN basic access also reached a good performances in HDSL environment. The combination of performance and relatively low complexity were essential for its acceptance. On the other side, QAM has the best combination of bandwidth, performance in the presence of noise and timing robustness. Trellis coded modulation may be also applied to either PAM or QAM to achieve coding in system performance.

The performance of QAM and PAM schemes with fractionally spaced equalization, on long loops at the extreme range of a CSA, are similar. Trellis coded modulation received with parallel decision feedback equalizer shows slightly higher coding gains when applied to QAM than it does when applied to 2B1Q. Also, it was shown that QAM has better tolerance to impulse noise than 2B1Q, [6].

AT&T has developed a variation on QAM, called carrier-less AM-PM or CAP. This scheme produces the same spectral shape as QAM, may be detected with the same equalization strategy and has the same performance as QAM. If compared with the QAM, the advantage of CAP reflects in some digital implementation efficiencies [7].

HDSL standards

HDSL technology enabled the transmission 1.544Mb/s in North America and replaced existing T1 lines. This HDSL two-pair technology comprises two full-duplex systems (dual-duplex) each carrying 784Kb/s.

A similar development of HDSL technology occurred in Europe. In 1996 ETSI adapted the dual-duplex standard for single-pair HDSL - ETR 152 [8], which enabled transmission of E1 payload with the line rate 2.32Mb/s. The single-pair version of HDSL is also known as a Symmetric single-line DSL (SDSL). The distance limit of a such system nears 3km/0.5mm, enabling one-pair low cost solutions.

Although ETSI made efficient single-pair HDSL system, ANSI did not accept the performance reduction from the its own two-pair system. This happened because loops in USA are generally longer than in Europe. However, the need for single-pair systems still existed and this led ANSI to start work on a new standard - HDSL2. HDSL2 uses a new transmission method, incorporating a new line code PAM 16, higher transmission power and special pulse shaping for spectral compatibility with other existing services. This code is called OPTIS which stands for Overlapped PAM Transmission with Interlocking Spectra. OPTIS achieves an improvement of up to 7 dB over the old 2B1Q HDSL. At the other side, OPTIS shows high complexity and high power required for such a system.

ETSI also accepted OPTIS method and decided to adopt it. The new method is implemented into ETSI-SDSL standard, providing multi-rate SDSL with better system's performance.

Service deployment

HDSL technology was ready for deployment in the early 1990s. Until now it has been widely installed for various business purposes. Figure 4. illustrates two typical HDSL applications. Although this figure depicts a single-pair HDSL system, it equally concerns two- or three- pair HDSL systems. Figure 4.a) refers to the access to E1/T1 network. It should be noted that an HDSL cabinet, that is a rack with multiple HDSL modems, usually exists at the central office.

HDSL technology is also successfully applied in fragments of the transit network, in order to eliminate the repeaters. The technical requirements in terms of bit error rate (BER), availability and reliability for such systems are more strict than for the application in the access network.

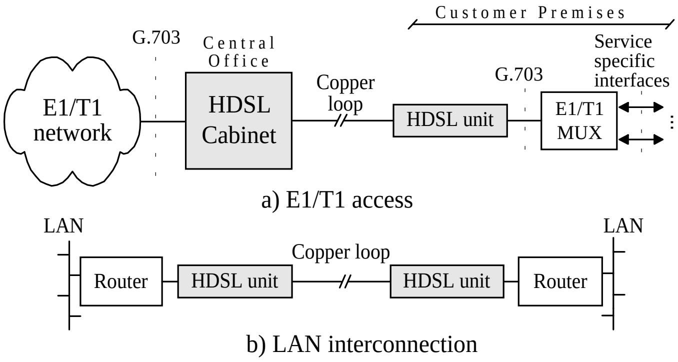

Figure 4. Typical HDSL utilization.

Another utilization of HDSL refers to the interconnection of local area networks – LANs. Figure 4.b) illustrates applying of HDSL modem pair equipped with a high-speed data interface, e.g. V.35 or HSSI. An HDSL unit can be equipped with the appropriate LAN interface, e.g., an Ethernet bridge, thus avoiding routers.

Finally, an instructive application of HDSL and SDSL is the cellular telephone network. An HDSL line may connect the base station to the mobile telephone switching office, which in turn may also be connected to the nearest PSTN central office by another HDSL/SDSL line.

IV ADSL TECHNOLOGY

While HDSL technologies were used for replacing E1 and T1 connections mainly for voice applications, another DSL technology was originally developed for residential video services - *Asymmetric Digital Subscriber Line* (ADSL). ADSL technology offers the asymmetric bandwidth characteristics, that is 1.544-8.448Mb/s in the direction from the network to the user (downstream) and 32-768kb/s in the direction from the user to the network (upstream). This feature fits in with the requirements of client-server applications, in which the client typically receives much more data from the server then he is able to generate. The examples of such applications are Web surfing, remote LAN access, video on demand, distance learning, etc.

ADSL multicarrier modulation

The idea of ADSL was generated at Bellcore laboratories in the late 1980s [9]. The first standard development effort was initiated by ANSI in 1993, but in took until late 1997 for the final standard to be agreed upon by both the ADSL Forum and ANSI. This standard adopted DMT (discrete multitone) modulation, thus emphasizing its predominance over other proposals such as QAM or carrierless AM/PM (CAP).

As the name implies, multicarrier modulation divides a channel into numerous QAM-modulated subchannels and transmits data on each one. The technique has a long history and considerable theoretical support as on optimum code, but has been troubled by the cost of implementation. In the early 1980's it was shown that multiple channels could be realized with digital techniques using a fast Fourier transform giving rise to DMT, the version of multicarrier used in ADSL.

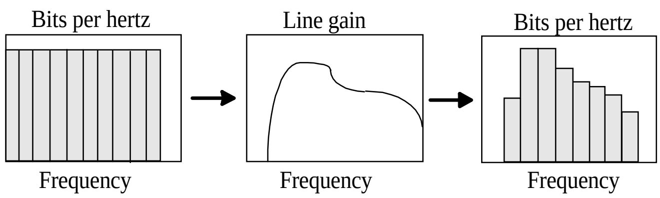

Figure 5. DMT bits per channel allocation.

The standard ADSL system uses 256 channels for the downstream data and 32 channels for the upstream. All channels have bandwidth of 4.3kHz and frequency difference between two adjacent channels is also 4.3kHz. Each channel can be modulated with QAM at up to 15 b/Hz. Theoretically, DMT could transmit 15.36 Mb/s over a line of zero length. Real lines and real implementation, of course, are not so promising, but rather than using adaptive equalizers to compensate for variations in line attenuation (single carrier systems), DMT spreads data over all channels according to the S/N ratio in each one. Figure 5. shows the adaptation process. During initialization a DMT modem measures the SNR per channel. and makes optimum use of the line by making optimum use of each subchannel. The available spectrum ranges from about 25kHz to 1.1MHz.

Support of bidirectional channels is provided by dividing the available bandwidth by Frequency Division Multiplexing (FDM), when non-overlapping bands are assigned for the downstream and upstream data. Another method is the echo cancellation in which bi-directional streams are assigned with the overlapping. At present only multicarrier ADSL modems have been implemented with echo cancellation.

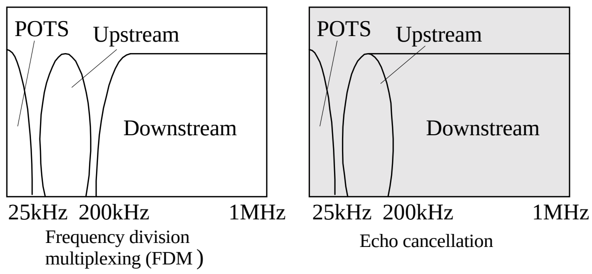

Figure 6. Channel configuration.

The channel allocation for two basic ADSL models is illustrated in Figure 6. Each model blocks off lower 25 kHz for POTS. An upstream channel with usable bandwidth on the order of 135 kHz takes the next slot. This channel selection scheme has the most favorable attenuation characteristics, but suffers the most crosstalk from other services such as IDSL (frequencies up to 80 kHz) and HDSL (frequencies up to 450 kHz).

ADSL System Architecture

A typical ADSL system architecture is illustrated in Figure 7. The ADSL functions at the network end (central office end) are performed by an ADSL Terminal Unit-Central office type (ATU-C) together with a splitter function (S-C). The ATU-C interfaces with the network switching, transport, and multiplexing functions and network operations. It may be located in a central office or in a remote location as an extension of a carrier system [9]. The ATU-C functions are usually integrated within a higher level network element, e.g. DSL access multiplexer (DSLAM). DSLAM contains the access interface (network termination – NT) to the appropriate transit network, e.g., ATM, Frame Relay, etc. ADSL functions at the customer end (remote end) are performed by an ADSL Terminal Unit-Remote end type (ATU-R) together with a splitter function (S-R).

At the customer premises, ATU-R may present the interfaces to the local distribution for broadband services via service modules (SM) and "set-top" boxes. The SM contains necessary decoders and terminal interfaces for the given service and customer control interfaces.

Splitters are three-node devices, that allow the telephony signals and the ADSL signal to reside on the same copper loop without interfering one with the other. The splitter provides a low pass filter to the basic voice and control telephony signal (below 4kHz) and a high pass filter for the ADSL signals, starting approximately at 25kHz or above. Most POTS splitter designs are passive, that is without powering requirements. The advantages of passive filters are in their reliability, because they enable continuous telephone service even if the modem fails (for example, due to a power outage). However, in some countries performance requirements direct the use of active POTS splitters.

Splitterless ADSL

In 1997 many ADSL vendors and carriers recognized that a reduction of speed could also simplify modem design. Reducing of hardware complexity was very attractive to vendors that wanted to implement DSL modems on the same DSP chips that are used in today's dial-up modems. Another driving force for development of splitterless ADSL was the need to easily install modem at the customer premises, without the telephone company intervening. A draft version of ITU-T recommendation specifying splitterless ADSL appeared in October 1998. with a working label G.lite. ITU-T approved G.lite specification in June 1999 as a recommendation G.992.2.

Splitterless ADSL is a subset of ADSL service. Simplification of full ADSL is achieved by eliminating the need for a POTS splitter at the customer premises, on the count of speed reduction (1.544 Mb/s downstream and 386 kb/s upstream). The splitteress ADSL system uses 128 frequency channels for the downstream data. In such scenario, the ADSL modem and the POTS operate together on the same home wiring system.

Service Deployment

The factor that decided mass deployment of ADSL services was the Internet. It seems that in 1999 both the technology and market have matured enough to let ADSL compete with cable-based Internet services. High-speed Internet access was also one of the key factors that accelerated the work on spliterless ADSL. It has been shown that access speeds at 10% of full ADSL capabilities are quite satisfying for surfing today's Internet. The spliterless ADSL is still 8 to 10 times faster than the ISDN services offered for Internet access.

An important feature that ADSL enables is full-time connectivity. The computer can always be accessible for real-time applications, automatic downloads, automatic upgrading of new software versions or using the computer as a telephone/videophone for Internet telephony.

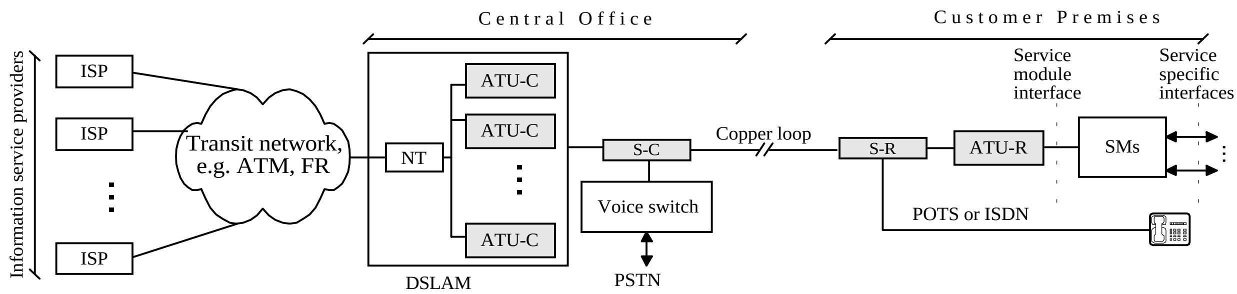

Figure 7. ADSL system architecture.

Although copper pairs are widely available, several line conditions may prevent the delivery of ADSL: first, if the telephone line to the customer premises is longer than 5.5km, second, existing of the load coils or an excessive number of bridged taps and third, that some portions of the telephone line is carried to the premises on fiber optic cable [4].

In the case of splitterless ADSL installation, existing of the POTS and ADSL signals on the same in-house wiring can make certain difficulties, because of the presence of noise generated from a telephone set in the same frequency range as the ADSL signal. Besides, the impedance of a telephone set when off-hook may be very low, thus significantly reducing the strength of ADSL signal. Experiences with various ADSL and telephone sets used on the same wiring were different, depending on the characteristics of the used telephone set [10], [11].

A simple solution to overcome the interference from the telephone set is to install an inexpensive in-line microfilter (low-pass filter) between the wall jack and the telephone. It should be noted that in this case filtering takes the form of a distributed splitter. If microfilters are installed properly on all telephone jacks, then a house may also get full rate ADSL [10], [11]. Another important problem with splitterless ADSL is the fact that home wiring has no standards and can be unsuitable for ADSL transmission. Often, the responsibility for maintenance of home wiring is undetermined, in which case the user has to concern about the whole wiring issue.

Finally, a common problem for ADSL and splitterless ADSL deployment refers to the installation at the personal computer - PC. Standards do not address the complexity of software and the drivers that are needed for PCs. Installations typically support only Windows 95/98/NT and Macintosh operating systems. Service is compatible with Linux or any other operating system that supports DHCP (Dynamic Host Configuration Protocol) negotiation. Customers who purchase a PC with the modem and appropriate drivers should not have this sort of problem.

V VOICE OVER DSL (VoDSL)

While HDSL technology has always comprised the integration of voice and data services, ADSL was initially proposed for packet video services and data traffic. The idea of integrating voice and data over the ADSL is today coming closer to reality through *Voice over DSL* –VoDSL.

In a typical voice over DSL configuration depicted in Figure 8., an integrated access device (IAD) resides at the customer premises. IAD converts voice traffic to IP packets or to ATM cells and combines it with the data traffic onto a single DSL line. In the central office, at a DSL access multiplexer (DSLAM), data is routed to the information service provider of choice. Voice packets are passed to a gateway, which converts them to traditional circuit switched traffic and further passes it to the PSTN. The gateway also handles functions associated with traditional telephone calls, e.g., call waiting, call forwarding, conference calling, etc. DSL can support up to 16 voice lines over a single copper pair.

By its nature VoDSL is best suited for small business users, like SOHO (Small Office Home Office). Although leading world companies like Nortel, Alcatel and Lucent Technologies have produced end-to-end VoDSL solutions and several field trials are currently taking place, VoDSL is still several years far from pervading to the market.

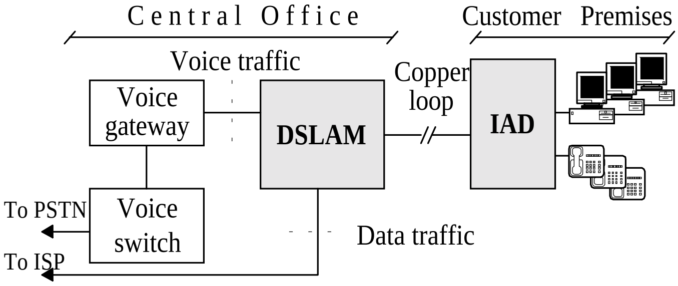

Figure 8. A typical VoDSL configuration [12].

Various technical and regulatory aspects, such as service level agreements, network management, relations between incumbent and competitive operators still have to be precisely defined.

VI VDSL TECHNOLOGY

Very high-speed Digital Subscriber Line (VDSL) is the next and highest-speed generation of DSL technologies. It enables delivery of data services of up to 52Mb/s in the last kilometer, over standard copper pairs. Support of both symmetric and asymmetric operations makes VDSL equally suitable for business and residential customers.

The bandwidth of asynchronous DSL offers very high throughputs suitable for current and upcoming Internet applications. Taking into account all service features of ADSL it is reasonable to ask what would trigger the need for the dramatic increase in bandwidth offered by VDSL. First application will probably be the delivery of symmetrical broadband services to small and medium enterprises and small/home office (SOHO). The capacity of tens of megabits per second is well coming, e.g., for publishers, movie editors, computer edit design engineers, scientific works at remote supercomputers, medical doctors assisting a surgery remote location, LAN emulation and high-quality video conferencing. As for residential application, one can perceive expensive trend of Internet traffic and a growing interest in video-on-demand-like services.

Three standardization groups are currently working on VDSL: ITU-T Study Group 15, ANSI T1E1.4 group and the ETSI TM6 group. Both ANSI and ETSI are working on two standards drafts. One of them considers DMT modulation, that is backward compatible with ADSL. The other is SCM (Single Carrier Modulation) based solution, that is not compatible with ADSL. SCM integrates the carrier-less amplitude/phase modulation (CAP) and quadrature amplitude modulation (QAM) technologies [13].

The DMT-based proposal is strongly favored by a number of leading chip set and DSL equipment manufacturers, including Alcatel, Nortel, Texas Instruments, NEC, Samsung, IBM and others. The SCM-based proposal is preferred by another group, including Lucent Technologies, Broadcom and Infineon (Siemens).

Very high speeds of VDSL are followed by specific environmental impairments that are not present in HDSL and ADSL. The VDSL transmission system shares its spectrum with different types of radio transmissions. As a result of cable unbalance these radio frequency signals can be received by telephone wires and may interfere with VDSL signal at the receiving side [13].

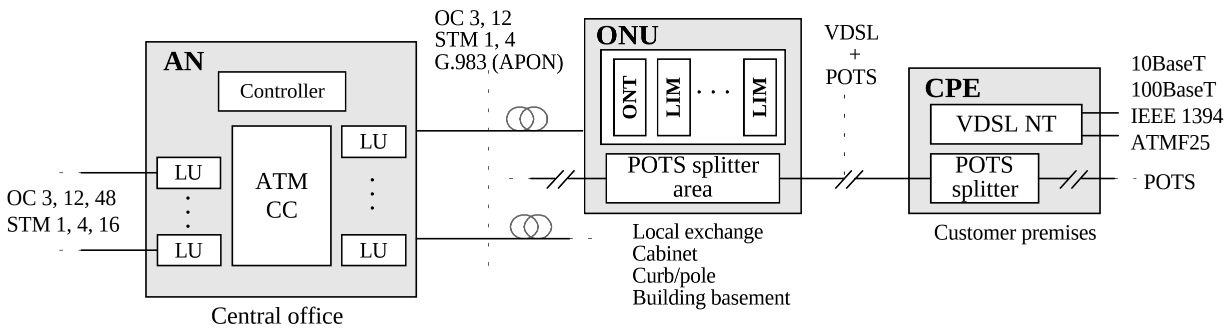

Figure 9. The general network model for VDSL deployment [14].

Access network architecture

Figure 9. depicts the general network model for VDSL deployment [14]. The main components of the access network are: access node (AN), optical network unit (ONU) and customer premises equipment (CPE).

AN is located at the central office, consisting of an ATM cross-connect (ATM CC) and a corresponding controller. It concentrates the traffic from various ONUs and directs it to one or more service providers. Interfaces towards the service providers afforded in the appropriate line units (LU) comprise synchronous digital network/ synchronous digital hierarchy (SONET/SDH) interfaces: OC3/STM1 at 155Mb/s, OC12/STM4 at 622Mb/s, or in the future OC48/STM16 at 2.5Gb/s. Interfaces towards the subscriber side include ATM passive optical network (APON) line units (ITU-T Recommendation G.983), or SONET/SDH line units at OC3/STM1 or OC12/STM4 rates. A typical capacity of AN is around 10,000 subscriber lines.

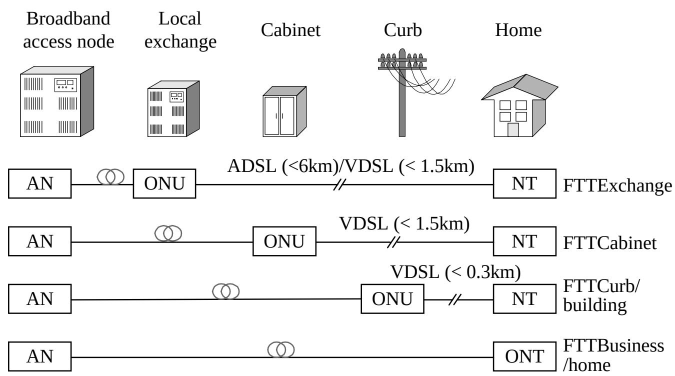

Figure 10. Fiber to the x topologies [14].

ONU contains VDSL line interface modules (LIM), the optical network termination (ONT) and the multiplexing function. ONT unit can be designed for APON interface or interface for SONET/SDH. A VDSL LIM unit usually supports multiple VDSL line terminations (LT). There are several "fiber to the x" (FTTx) topologies depending on the place of ONU, as illustrated in Figure 10. The length of the copper loop determines the type of xDSL technology which can be applied, as well as the bandwidth available to the end user. The overall capacity of ONU varies from 10 to 1000 VDSL lines, depending on the type of FTTx topology [14].

CPE contains VDSL network termination (NT) which represents the demarcation point between the access network provider and a private network. VDSL NT can be a single VDSL modem, equipped with one or more standard interfaces, as indicated in Figure 9. For business applications, modem can be connected to a LAN or a PABX. For residential users, modem can be connected directly to a multimedia terminal (PC, TV set or set-top box) or to a residential gateway.

Deployment perspectives

VDSL requires a significant initial investment in cable infrastructure and street cabinets. Development of optical technologies seems to accelerate deployment of fiber in the access network.

The search for a generic and economical optical technology that can be applied to any FTTx scenario resulted in development of APON, where a number of field trials is already running [14]. On the other side, SONET/SDH can be used for FTTCab or FTTExchange. SONET/SDH has already been well-proven in the transport networks, so operators could easily expand it to broadband services in the access network. The disadvantage is higher cost of such solution. For a long term, new optical access technologies have been investigated, including dense wavelength division multiplexing (DWDM), SuperPON, etc.

VII TECHNICAL ASPECTS OF XDSL DEPLOYMENT IN THE UNBUNDLING PROCESS

Unbundling is a process of allowing alternative (competitive) operators to use copper pairs installed and owned by incumbent (monopoly) operators. This process is currently taking place in many countries worldwide, including technical, economical and legal problems to be simultaneously resolved. In this section we address several engineering aspects of the unbundling process, considering providing of xDSL services.

Unbundling includes three principal methods of access to copper pairs: direct access, bitstream access and frequency access [15].

Direct access means that competitive operators have access to the twisted copper pairs and may use them according to the regulations. Typical problem refers to limits on the power spectral density by various transmission systems. Bitstream access is also called service unbundling. Competitive operators may offer services to the end users, while the incumbent operator fully controls copper pairs. Frequency access means that fractions of the spectrum in a single copper pair are allocated to different operators. In this case miscellaneous telecommunication services can be independently allocated to different providers.

Older transmission systems like HDB3 (high-density bipolar 3) use local loops for implementation of E1/T1 or ISDN primary rates. The HDB3 deteriorates performances of all xDSL systems.

Different types of xDSL services may lead to crosstalk interference between systems and performance degradation. The crosstalk addresses several issues that have to be resolved and may influence modem design and engineering. VDSL systems installed in a bundle use shorter loops with a high data rate. Due to this, xDSL systems operating with lower capacity on longer loops in the same bundle may be seriously degraded by far-end crosstalk (FEXT). On the other side, all systems operating in the same bundle must apply the same frequency plan in order to avoid near-end crosstalk (NEXT). Frequency plan encompasses allowed bit rates according to loop length and the allowed asymmetry ratio (the ratio between upstream and downstream rates).

Finally, aside from predictable technical difficulties, finding out why a line does not fit for xDSL service can be a serious task. Only incumbent operators can really comprehend why a line cannot deliver xDSL, but often they don’t test each line to discover the problem. Under such conditions, appropriate regulatory actions are necessary to enforce the incumbent operators to resolve the problem.

VIII DEVELOPMENT OF XDSL MODEMS BASED ON CHIP SETS

Leading world chip-set manufacturers today offer a wide spectrum of xDSL chip-set solutions. These solutions usually include digital signal processor (DSP) and analog front end (AFE) circuits, which together compose an xDSL transceiver. DSP performs all the digital functions necessary to achieve a high quality, echo-free signal with optimal decoding. These functions may include: an appropriate modulation/ demodulation, encoding/decoding algorithms, scrambling/ descrambling, adaptive echo canceling, linear equalization and timing recovery. AFE is typically a single chip which includes A/D and D/A converters. Besides xDSL chip sets should include various mapping and framing functions, depending on the type of technology. The DSP and the framer are controlled and configured by an external general purpose controller - modem host. All programmable coefficients and parameters are loaded by this controller. The host also handles initialization procedure and performs the monitoring and adaptive functions.

Development of a modem using particular chip-set solution comprises: design of microcontroller environment, modem interfaces and power unit. Software design can be significantly simplified, since basic software drivers for programmable chips are usually available. A brief overview of leading xDSL chip-set manufacturers and their products can be found in [16].

The PP-HTU2 HDSL modem design

PP-HTU2 is an upgraded variant of the HDSL modem PP2M1p [17], which are both developed in the Telecommunication Department of Mihajlo Pupin Institute. PP-HTU2 is a stand-alone, single-pair modem designed according to the ETSI standard ETR-152 [8]. An improved variant of 2B1Q modulation is applied, as described previously in section III. On the DTE side modem supports: non-channelized ITU-T G.703 interface, V.35 data interface or an additional Ethernet module interface.

Block scheme of the PP-HTU2 modem is depicted in Figure 11. Design is based on the Metalink MtH2400 HDSL chip set, which comprises: Mapper/Framer (M/F), customized DSP and AFE. M/F and DSP are programmable circuits, which are controlled by the modem host. Basic M/F and DSP software drivers are provided by chip set manufacturer.

M/F circuit is configured to satisfy the requirements for non-channelized HDSL system implementation. M/F forms a HDSL core frame, preserves the integrity of user data, supports application requirements and provides resources for specific O&M functions. M/F adds HDSL overhead to the user data, including an 8-bit embedded operation channel (EOC) and 48 Z bits, available for O&M and control functions [8]. Thus, the total bandwidth available for control operations equals 9.3kb/s.

DSP implements all adaptive algorithms. The most important of them are echo canceling, noise prediction and equalization. The last is approximation of Maximum Likelihood Decoder implemented as a multiple adaptive Decision Feedback Equalizers (DFE), which exhibits superior performance over the conventional DFE with range extension of up to 25%.

AFE is completely customized circuit, which together with DSP composes a HDSL transceiver for single pair applications.

Host is a standard 80c32 microcontroller with a corresponding environment. DTE line interface units (E1 LIU and V.35 LIU) are designed using commercially available components. Ethernet self-learning bridge module IR-ETH providing either 10BaseT (UTP) or 10Base2 (BNC) LAN interface is also supported. Serial interface unit (SIU) provides support for RS 232 serial interface to connect the modem with the supervisory PC terminal.

The PP-HTU2 O&M System

O&M functions implemented in PP-HTU2 modem comprise the following: modem reset control, DTE equipment identification, start-up procedure control, support of various control loopbacks, BER testing, loss of carrier detection, loss of frame synchronization detection, alarm reporting,

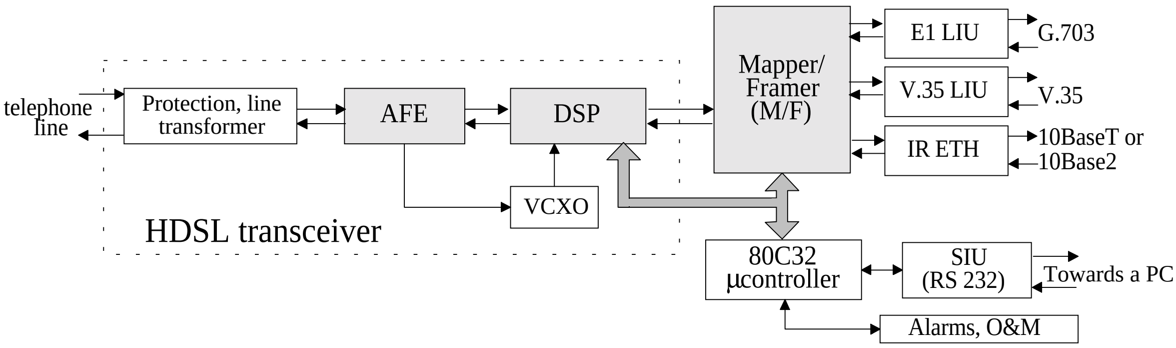

Figure 11. Block diagram of the PP-HTU2 HDSL modem.

monitoring of transmission quality and performance monitoring according to ITU-T Recommendation G.826. Operator can control point-to-point link between a pair of PP-HTU2 modems by means of a standard PC, with Windows95/98/NT operating system. PC should be connected to one of PP-HTU2 modems by serial RS-232 interface. This modem should be referred to as local, while the other is remote. A dedicated Windows application for HDSL system supervisory and control has been developed. Details on this application are presented in [18].

The exchange of control information between local and remote PP-HTU2 modem is performed by means of Z bits in the HDSL frame overhead. Figure 12. illustrates the basic protocol implemented for the exchange of O&M information.

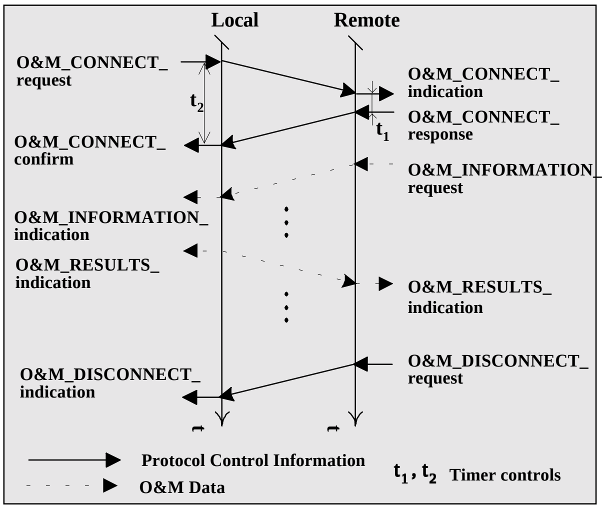

Figure 12. Basic protocol for O&M information exchange.

BER test and main loopback controls can be initiated either from the PC terminal or from the modem front panel (local or remote) by pressing the proper button. During the execution of these commands the appropriate LED indications have to be turned-on. Operations can be terminated either from the PC or front panel, independently on the initiating device.

IX CONCLUSIONS

While HDSL technology has been deployed in business applications since middle 1990s, ADSL is today in a real expansion in developed countries for high-speed Internet access. Considering existing performances of current global Internet, as well as economical reasons, splitterless ADSL seems to be particularly interesting solution for residential customers. VoDSL is an emerging technology which has an ambition to provide simultaneous transmission of up to 16 voice lines and ADSL over a single copper pair. The highest-speed xDSL technology which seems to be equally suitable for business and residential customers is VDSL. Its standardization is not yet finished and deployment strongly depends on the fiber optic FTTx technology deployment.

Unbundling is currently taking place in many countries. A proper regulatory activity is extremely important in such situation, in order to create an environment that encourages fast progress to mass deployment of xDSL.

At last, leading manufacturers supply various xDSL chip set solutions together with basic software drivers and appropriate application guidelines. This forms a solid base for xDSL products development, as well as their affirmation in developing countries.

REFERENCES

[1] D.T.Huang, C.F.Valenti, “Digital Subscriber Lines: Network Considerations for ISDN Basic Access Standard”, *Proc. of the IEEE*, vol.79, no.2, Feb. 1991, pp.125-144.

[2] J.W. Lechleinder, "High Bit Rate Digital Subscriber Lines: A Review of HDSL Progress", *IEEE JSAC*, vol. 9, no.6, Aug. 1991, pp. 769-784.

[3] J-J. Werner, "The HDSL Environment", *IEEE JSAC*, vol.9, no.6, Aug. 1991, pp. 785-800.

[4] “Special Report: Digital Subscriber Lines” (E.Clark eds.), *Network Magazine*, April 2000, pp. 43-62.

[5] Q4/SG15 Home Page, URL: http://www.kiwin.com/ xdsl/00_SG15Q4_home_page.html.

[6] K. Sistanizadeh, K.Kerpez, “A Comparison of Passband and Baseband Transmission Schemes for HDSL", *IEEE JSAC*, vol. 9, no. 6, August 1991, pp. 885-894.

[7] K.Maxwell, "Asymmetric Digital Subscriber Line: Interim Technology for the Next Forty Years", *IEEE Comm. Mag.*,vol. 34, no 10, Oct. 1996, pp. 100-106.

[8] ETSI, ETR-152, December 1996.

[9] P.J. Kyees et all., “ADSL: A New Twisted-Pair Access to the Information Highway”, *IEEE Comm. Magazine*, vol. 33, no.4, April 1995, pp.52-59.

[10] Orckit DSL Knowledge Center, URL: http:// www.orckit.com/orckit_dsl_center.html.

[11] A. \or|evi}, S. \or|evi}, N. @ivi}, “The New Use of Copper Lines: xDSL technology”, (in Serbian), paper accepted for *NTP VJ Magazine*, 2000.

[12] A.Karve, “Emerging Technology: Voice over DSL”, *Network Magazine*, November 1999, pp. 63-68.

[13] V.Oksman, J-J.Verner, “Single Carrier Modulation technology for Very High-speed digital subscriber Line”, *IEEE Comm. Magazine*, vol.38, no.5, pp. 82-89, May 2000.

[14] P.Vetter et all., “Systems Aspects of APON/VDSL Deployment”, *IEEE Comm. Magazine*, vol.38, no.5, pp. 66-72, May 2000.

[15] P.Odling et all., “The Technical Impact of the Unbundling Process and Regulatory Action” *IEEE Comm. Magazine*, vol.38, no.5, pp. 74-80, May 2000.

[16] L.Goldberg, “DSL Technologies: Ready for Takeoff?”, *Electronic Design*, vol.47, no.13., June 1999.

[17] V.Krsti} et all., “The Chip Set HDSL Modem: Design and Performance Evaluation”, TELSIKS’99.

[18] D.Vukoti}, S. \eni}, “ Realization of the software for the PP-HTU2 HDSL modem supervision and control”, (in Serbian), paper submitted for TELFOR’2000.

Abstract: This paper addresses basic features of xDSL technologies, focussing on modulation techniques, access network architecture and deployment problems. Technical issues of xDSL deployment in the unbundling process are also discussed. A description of a HDSL modem PP-HTU2 developed in Mihajlo Pupin Institute is presented, focussing on the implementation of O&M system. Development of this modem represents an instructional example of possibilities to follow leading manufacturers and stimulate xDSL deployment in developing countries.

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