Offering Video Services over Twisted Pair Cables to the Residential Subscriber by means of an ATM based ADSL Transmission System

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ABSTRACT

With the current deregulation in the telecommunication market and the associated competition with CATV companies, Public Telecommunication Operators (PTOs) are faced with the technical challenge to provide switched video services over twisted pair cables in a cost-effective way. The so-called Asymmetric Digital Subscriber Line (ADSL) transmission system could provide the answer to this need. ADSL is characterised by a downstream bitrate (from Central Office to Residential Subscriber) of a few Mbit/s and an upstream bitrate (in the other direction) of some hundreds of kbit/s, both multiplexed on a conventional twisted pair on top of the analog telephone service. Because of its asymmetric character in terms of bandwidth provision, ADSL is particularly suited for the transport of video services such as video-on-demand (VOD), networked CD-I,... in which the upstream bitrate is essentially limited to control information.

The present paper focuses on the service provisioning over ADSL based on ATM transport. The support of ATM over ADSL offers a flexible transport system for the provision of new medium to high bitrate services, while it guarantees a gradual evolution for the provision of B-ISDN services towards the Residential Subscriber. In this paper, the ATM related functional blocks of the ADSL system are described in more detail.

KEYWORDS : Access Networks, Twisted Pair Cable, ADSL, B-ISDN, DMT, VOD.

1 INTRODUCTION

While the evolution of the copper plant to fiber optic is in progress and fiber is the target transmission media chosen for B-ISDN, there is an urgent need to explore new technologies for immediate application to meet the requirements of those customers who have wide band service needs at this moment. Digital Subscriber Loop (DSL) techniques allow, through the use of digital signal processing, to transport high-rate services over the existing copper-based infrastructure. The state of the art allows the transport of signals of a few Mbit/s over some kilometers of twisted pair cables while assuring a BER on the order of 10^{-7} or better.

2 ADSL : A TRANSMISSION TECHNOLOGY ON UNCONDITIONED TWISTED PAIR

A copper twisted pair cable is the basic access connection of a telephone user to the telephone network. The frequency band used for the transport of the analog signal ranges from 300 Hz to 3.4 kHz. Thanks to the use of digital signal processing techniques, Digital Subscriber Loop (DSL) techniques are able to transport high bitrates over the existing copper twisted line simultaneously with the analog POTS (Plain Old Telephone Service).

Although in this paper we focus on the ADSL system (Asymmetric DSL), the basics are also valid for other DSL systems that are currently available or planned, such as HDSL (High-speed DSL) and VHDSL (Very High-speed DSL). The former system (HDSL) offers 1.5 or 2 Mbit/s bi-directional data transport over 2 or 3 twisted pairs (without repeaters) and is intended as a mere replacement for T1/E1 repeatered lines in the distribution plant. Therefore, it is often referred to as 'repeaterless T1/E1'. The latter system (VHDSL) is intended to provide very high bitrate services (> 10 Mbit/s) over short distances (less than 1 kilometer) although it is shown that the transmission of 15 Mbit/s over mid-CSA (Carrier Serving Area) loops of more than one mile is feasible [1]. The ADSL transmission system offers an asymmetric capacity to the Residential Subscriber. In the direction towards the subscriber, the ADSL system provides a capacity between 1.5 and 6 Mbit/s. The bandwidth in the opposite direction is in the range from 16 to 640 kbit/s.

The transmission channel capacity depends primarily on the twisted pair characteristics and suffers from a number of impairments. The frequency dependent attenuation and dispersion leads to inter-symbol interference. Moreover, as coupling exists between wire pairs in the same binder or adjacent binder groups, crosstalk limits the transmission capacity of the copper loop. Furthermore, some subscriber loops have open-circuited wire pairs tapped onto the main wire pair, called bridged taps. The presence of bridged taps in the loop plant differs from country to country and depends upon the cabling rules used in the past. Their presence causes reflections and affects the frequency response of the cable, leading to pulse distortion and inter-symbol interference. A loop can also be built up of wires with different diameters (referred to as gauge transitions), leading to reflections and distortion as well. Further, copper transmission suffers from impulsive noise that is characterised by high amplitude bursts of noise with a duration of a few microseconds to hundreds of microseconds. It can be caused by a variety of sources such as Central Office switching transients, dial pulses and lightning. Lastly, the impedance mismatch between the hybrid transformer, responsible for the split between transmitter and receiver channel, and the line impedance causes unwanted reflections. This problem can be resolved either by echo-cancellation or by separation of upstream and downstream transmission by means of Frequency Division Multiplexing (FDM). To encompass the cited imperfections of the copper twisted pair, a highly adaptive transmission system is needed.

The ANSI T1E1.4 committee is currently standardising Discrete Multi-Tone (DMT) as the line code to be used in the ADSL transmission system [2]. In essence, the DMT system consists of a number of sub-channels, referred to as tones, each of which is QAM-modulated on a separate carrier. The carrier frequencies are multiples of some basic frequency (4.3125 kHz). The available spectrum ranges from about 20 kHz to 1.104 MHz. The lowest carriers are not modulated to avoid interference with POTS. The bandwidth used for upstream transmission is considerably lower than that used in the opposite direction. The up- and downstream spectra can overlap in case echo cancelling is used. The alternative is the use of Frequency Division Multiplexing (FDM) in which case no tones are shared by up- and downstream transmission. Both alternatives are accepted by the ANSI T1E1.4 committee. The latter case is depicted in Figure 1.

The transmit power spectrum is (almost) flat over all used tones. The number of bits assigned to a tone is determined during an initialization phase as a function of the transmission characteristics as well as of the desired bitrate.

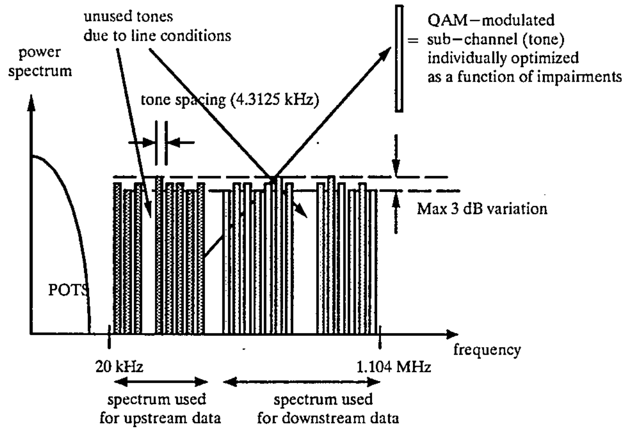

Fig. 1 : DMT Power spectrum for FDM case (conceptual drawing)

During operation, adaptation of this bit assignment is possible to compensate for variations in line conditions.

In order to improve the bit error rate in the ADSL system, Forward Error Correction (FEC) is applied. ANSI specifies the use of Reed-Solomon coding, combined with interleaving. The additional use of Trellis coding is optional but may further reduce the BER or increase the SNR (Signal to Noise Ratio) margin of the system for a given BER. For further details on the line coding and error correction techniques we refer to [3] and [4].

In the ANSI T1E1.4 working draft [2], special attention has been given to a service specific interface, referred to as the 'channelized interface'. This interface is based on a specific framing structure that can provide a combination of ADSL bearer channels envisaged up to now. In the current version, seven bearer channels can be transported simultaneously over ADSL : up to 4 downstream simplex bearers and up to 3 duplex bearers. The three duplex bearers could alternatively be configured as independent unidirectional simplex bearers, and the rates of the bearers in the two directions (network towards customer and vice versa) do not need to match. The bearer channel data rates can be programmed with a granularity of 32 kbit/s. Other data rates (non-integer multiples of 32 kbit/s) can also be supported, but will be limited by the ADSL system's available capacity for synchronization.

3 ATM PROVISION OVER ADSL

The variable bitrate inherent in ADSL ensures, in principle, the flexibility to support new services with other bitrates than those envisaged at the moment and to take advantage of the decrease of the required bitrate. This certainly holds for video services where thanks to the advance of video compression techniques full motion video images can already be offered with reasonable quality at low bit rates from 1.5 to 6 Mbit/s. However, this inherent flexibility of the ADSL modem is limited by the definition of the framing structure combined with the definition (and standardization) of consistent physical interfaces.

Therefore, it is advisable to offer a flexible transport mechanism that is future safe, adaptable to the varying demands in bandwidth and that can rely on a flexible switching technique. The Asynchronous Transfer Mode (ATM), which is recognized by the ITU as the universal transfer mode for B-ISDN, offers this flexibility [5]. Moreover, when the ADSL system provides an ATM interface, a gradual evolution can be planned for the provision of B-ISDN services to the Residential Subscriber. B-ISDN envisages a full fiber based access network, which involves large investments from the telecom operator companies as the present access network is merely based on copper twisted pair. By providing ATM over ADSL, ATM based services can be offered to the Residential Subscriber already now while the access network is evolving towards a full fiber based network (FTTC, FTTB, FTTH : fiber to the curb, the building or the home). Meanwhile, for the subscribers and service providers the ATM cell transport over twisted pairs by means of ADSL technology remains transparent and emerging new services can be introduced rapidly and independently of the state of evolution towards a fiber based access network.

As the ADSL transmission system offers a large bandwidth to the Residential Subscriber while still offering a reasonable upstream bandwidth capacity, it is specifically tailored to services that are asymmetric in terms of the bandwidth such as Video On Demand (VOD) [6]. As video compression techniques improve, several VOD services could be offered simultaneously to the subscriber by means of the ADSL system. With an ATM based ADSL system, the VOD service is independent of the state of video compression and full transparency is guaranteed between VOD server and VOD set-top unit at the Residential Subscriber. For the deployment of a VOD service, a mix of access network techniques (FITL, ADSL, coax) will be applied. When full ATM transparency is assured, there is no need for interworking functions in the access network.

The envisaged network architecture for the ADSL system based on ATM is designed with the evolution of the access network in mind. The ATM interface towards the Residential Subscriber is referred to as ATU-NT (ADSL Terminating Unit - Network Termination) while the interface towards the Central Office (CO) is here referred to as ATU-LT (ATU - Line Termination). Means are provided to operate the ADSL segment as an independent part in the access network. In this way, the ADSL system can interface on the LT side directly to an ATM switch in the Central Office or to a fiber based access network with ATM transport. Though the primary aim is the integration with a set-top unit for VOD service provision at the Residential Subscriber, the ATU-NT can provide access to various types of Service Modules (SM) as depicted in Figure 2.

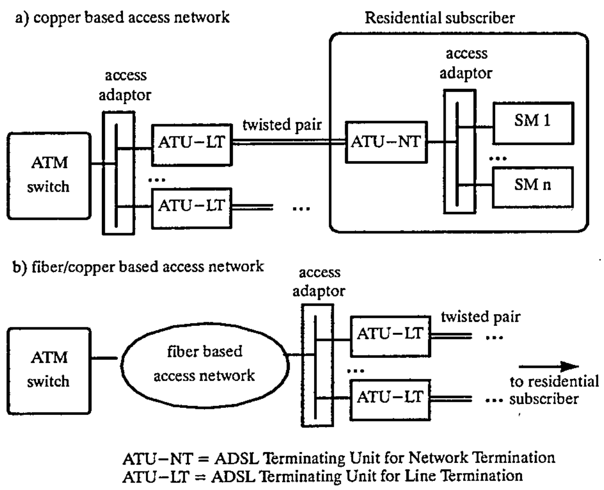

Fig. 2 : Access Network Configurations

In the next paragraph we will further discuss the ATM related functional blocks of the ADSL termination units ATU-LT and ATU-NT.

4 FUNCTIONAL DESCRIPTION (ATM RELATED) OF THE ADSL TERMINATION UNITS

In an ADSL system, the DMT modem part can be isolated from the service interface. Between both, a specific interface can be defined. The modem part is completely independent of the way in which different services are provided to the user and of how these services interface with the network. Figure 3 depicts the top level functional blocks of the ADSL system currently designed at Alcatel Bell. The system provides an ATM interface and basic ATM functions. Input from a channelized bitstream is also possible. The following paragraphs focus on the ATM functional blocks.

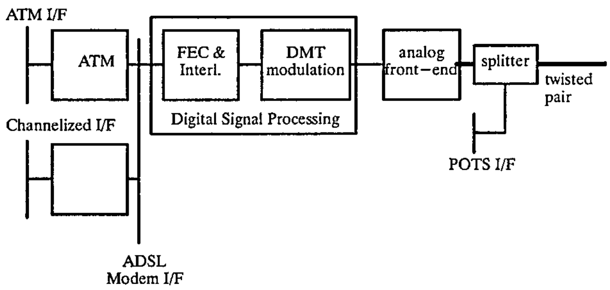

Fig. 3 : Interfaces provided in the ADSL System

Mapping an ATM cell stream into a specific channel of the channelized interface could be done but this is far from optimal. It introduces extra overhead and limits the full ATM flexibility by defining a rigid physical interface. This is the case in ANSI where a downstream channel in the framing structure can be reserved for ATM transport. In the current version of the standard [2], the ATM cell rate is restricted to multiples of 1.732 Mbit/s, rounded up to the nearest integer multiple of 32 kbit/s. Moreover, no upstream ATM transport is provided in the ANSI recommendations. To overcome these limitations, it is desirable to offer the ATM functional block a direct interface to the digital signal processing block. In what follows, we will refer to the 'ADSL or DMT modem function' as the group of functions including FEC (Forward Error Correction), Interleaving, DMT modulation and Analog front–end.

The ADSL modem interface ensures transparent transmission of data with a downstream bandwidth (from Central Office to Residential subscriber) of up to 6.784 Mbit/s and an upstream bandwidth (in the opposite direction) of up to 640 kbit/s over one unconditioned twisted pair. Besides, it provides two distinct transmission channels referred to as the Slow and the Fast channel (Figure 4). The data stream on the Slow channel is interleaved after FEC, before it is passed to the DMT modulator. This improves the error correction capability at the expense of extra delay. The Fast data is not interleaved and has a lower delay, while the error correction capability is smaller.

The maximum useful downstream and upstream bitrates depend upon the twisted-pair characteristics. The ATM functional block (de)multiplexes the received ATM cell stream (to) from the Slow and Fast transmission channels. Both cell streams are treated in an independent way. The (de)multiplexing function is based on the ATM header content, for which a specific context table is provided, that can be updated dynamically.

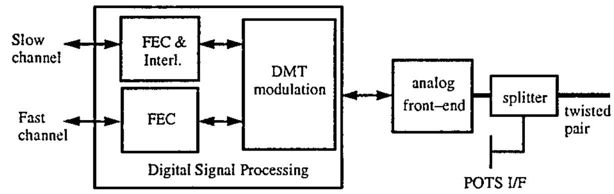

Fig. 4 : Fast and Slow Channels provided by the DMT Modem

When the ADSL system is integrated in a larger access network (e.g. in a hybrid fiber and copper access network), two Quality Of Service (QOS) classes can be defined on the ADSL transmission system : the Fast channel with a low delay but larger BER and the Slow channel with better BER performance but larger delay. At connection setup, a choice will be made between Fast and Slow channel depending on the QOS requirements of the invoked service. The above mentioned multiplex/demultiplex function of ATM cells is based on the full header (including the VP). Therefore, the ADSL system can be incorporated in an access network where the QOS management is VP based.

An overview of the ATM functional block is provided in Figures 5 and 6.

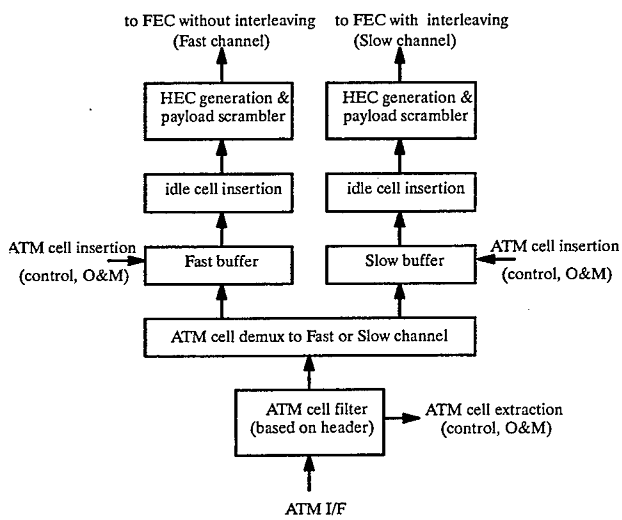

Fig. 5 : ATM Functional Block (from ATM Interface to DMT Modem)

The ATM transport on the ADSL transmission system is cell based. In the direction towards the DMT modem the bitrate adaptation to the DMT modem characteristics is provided by means of idle cell insertion.

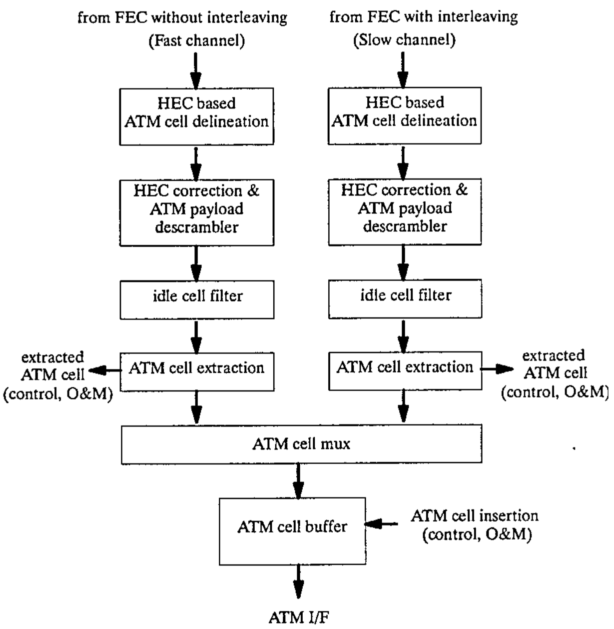

Fig. 6 : ATM Functional Block (from DMT Modem to ATM Interface)

The chip set is able to operate on both terminations : at the Residential Subscriber (ATU-NT) and at the Central Office (ATU-LT). The functions to be performed by the ATM interface are essentially the same for both ADSL terminations, but the transmit/receive bit rates are different. Therefore, the Fast and Slow buffers are able to serve the bitrates downstream as well as upstream.

Cell delineation on the received ATM stream is based on the HEC field in the ATM header and is conform to ITU recommendation I.432 [7]. Therefore, the correct HEC field (conform to [7]) is inserted in the ATM header at the transmit side (direction to DMT modem). In order to ease the delineation process, payload scrambling is performed at the transmit side. Specific performance monitoring is done on both the Fast and Slow transmission channel by the HEC error detection and correction block. After idle cell filtering and cell extraction, both ATM cell streams from the Fast and Slow channels are multiplexed on a single ATM stream. An ATM cell buffer serves the output ATM interface.

The ATM interface can be used in a bus configuration : either as a slave component in the ATU-LT, or as a master component in the ATU-NT (see Figure 2). The former allows to connect several ADSL systems on a single network termination (e.g an SDH STM-1 interface), while the latter permits several service modules to be connected to the ADSL system.

For operation and maintenance, the ATM interface provides insertion and extraction of ATM cells in both directions (from and to the DMT modem) and on both the Fast and the Slow channel. Cell extraction is based on the ATM cell header. The extracted cells are processed in an On-Board Controller (OBC). In this way, operation and maintenance of the ATM transport in the ADSL system can be performed autonomously. The cell insertion to and extraction from the ATM interface is also used for signalling purposes (e.g. for allocation of VP/VC resources in the ADSL system). Specific VP/VCs can be defined dynamically.

Besides, the ADSL system provides means to perform tests in various loop-back configurations on the system in operation.

5 CONCLUSIONS

In this paper we have discussed the advantages of providing an ATM interface on an ADSL system.

On the one hand, ATM based services can be offered to the Residential Subscriber while the access network is still in evolution towards a full optical network. On the other hand, B-ISDN can benefit from the excellent marriage between the VOD service and the asymmetric bandwidth offered by ADSL. VOD is expected to become popular and can be used as a trigger for the introduction of other B-ISDN services thanks to the flexibility of ATM in terms of bandwidth allocation.

6 REFERENCES

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