TI DSP IMPLEMENTATION OF A MEDIUM SPEED DSL (MDSL) FOR MULTIMEDIA APPLICATIONS

Song Wu, Xiao-Lin Lu, and Walter Y. Chen
Texas Instruments, Inc.
DSPS R&D Center

ABSTRACT

High performance general purpose Digital Signal Processor (DSP) provides a cost efficient solution for broadband Digital Subscriber Line (DSL) transceiver. A DSL modem with a transmission throughput between 400 kbps and 2 Mbps operating over most of existing telephone subscriber loops has been implemented on a single TI TMS320c548 DSP for consumer multimedia applications such as internet access. Except the Analog Front End (AFE), all the Discrete Multitone Modem (DMT) algorithms are implemented with DSP software. DSP based software DSL modem also provides a convenient interface to Microsoft point-to-point protocol (PPP) for network access.

1. Introduction

Asymmetric Digital Subscriber Line (ADSL) is a technology to deliver up to 8 Mbps downstream and 1 Mbps upstream duplex data rate from telephone company's central office to residential home using existing twisted copper pair. The standard[1] has been defined by ANSI standard committee to use Discrete Multi-Tone modulation scheme as line code and support four asymmetrical downstream and three duplex channels. The standard was intentionally defined for video on demand (VOD) applications. It requires the minimum data rate of 1.5 Mbps at the distance reach of 18 kft respectively. However, as internet access market emerging, it is highly desirable to have a low cost solution targeting at the consumer market.

Medium-rate Digital Subscriber Line (MDSL) provides an ideal solution to this internet access market. Our MDSL chooses modified DMT modulation scheme and has rate adaptive capability. The data rate is negotiable between central office and remote modems depending on the line condition. In fact the MDSL DMT can provide data rates up to 2.8 Mbps downstream and 844 kbps upstream. The data rate can also be negotiated down with 16 kbps per step. More importantly the MDSL DMT technology implemented on a general purpose Digital Signal Processor (DSP) gives a cost effective and flexible DSL modem available today. The DSP software based MDSL DMT allows itself to be integrated with current 56 k, V.34 and ISDN, etc., commercial modems on a single chip and can be easily upgraded with downloadable software in future.

2. MDSL spectrum allocation

Similar to the ADSL technology MDSL is designed to carry the packetized data through the same phone line with a traditional POTS service.

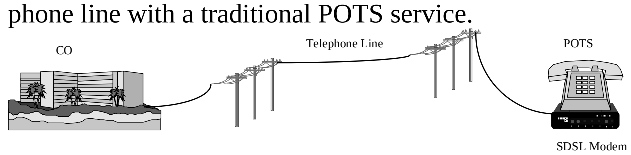

Figure 1. A Subscriber Loop for DSL

Within a total bandwidth of about 1 MHz, the DC to 10 kHz is reserved for POTS, the spectrum from 20 kHz above can be used for DSL applications. In this frequency range, the impairments from cross talk will deteriorate the modem performance. NEXT and FEXT from other foreign DSL systems sharing the same loop plant could limit the transmission throughputs. Figure 2 shows the signal to self Far End Cross Talk (FEXT) and background noise ratio for 1, 2, and 3 miles of 26 gauge twisted pair loops assuming a transmit power density of -40 dBm/Hz and a receiver front end background noise power density of -140 dBm/Hz. In Figure 2, the simplified 26 gauge loop model is expressed as $\left|H(f)\right|^2 = e^{-2d\left(k_1\sqrt{f}+k_2 f\right)}$ for $k_1 = 4.8\times10^{-3}$ and $k_{21} = -1.71\times10^{-8}$, where f is in unit of Hz and d is in unit of mile. The SNR could be reduced if Near End Cross Talk (NEXT) and FEXT noise from other foreign DSL systems such as ISDN, High-bit-rate Digital Subscriber Line (HDSL), and Asymmetrical Digital Subscriber Line (ADSL) are to be considered.

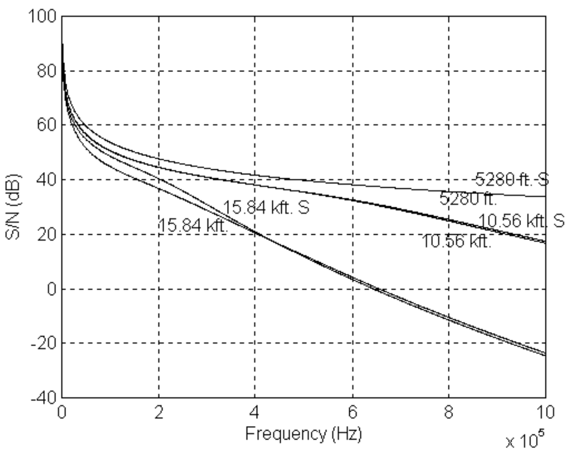

Figure 2. Signal to FEXT and Background Noise Ratio

To avoid interference with other DSL service, MDSL spectrum has to be compatible with that of ADSL. Therefore, MDSL selects the same upstream spectrum band as that of the ADSL, and selects the downstream spectrum band as the subset of ADSL downstream band. As shown in Figure 2, for long DSL loops the spectrum above 600 kHz is actually un-useable. MDSL system therefore uses 20 - 140 kHz as upstream band and 180 - 640 kHz as downstream band. The spectrum such selected is compatible to ADSL spectrum and therefore will not cause problems for other DSL service in the same bundle.

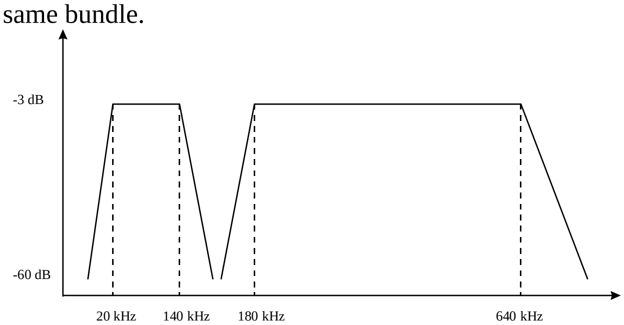

Figure 3. MDSL upstream and downstream spectrum

3. Minimize the System Cost

The design goal of MDSL modem is to minimize the system cost and power consumption at both client side and central office side. At the client side, since modem receiver has to cover the broader bandwidth, the cost will contribute the most to the overall system. The cost reduction on the client modem has to be balanced between the analog front end (AFE) and the DSP. The MDSL system has been designed to achieve a maximum 2.8 Mbps downstream date rate at shorter loop, and 500 kbps at 18 kft with a total signal processing power of only 70 Mips.

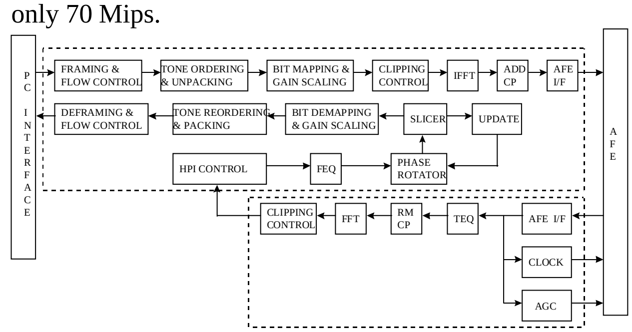

Figure 4. MDSL client modem receiver block diagram.

Figure 4 shows the MDSL DMT receiver block diagram. The frequency band from DC to 640 kHz has been equally divided into 128 frequency bins. 256 samples are therefore needed for the receiver FFT. To reduce the taps requirement on the time domain equalizer (TEQ), 64 samples of circular prefix have been added in front of 256 samples actual data.

In the client modem transmission path, 32 frequency bins are used for upstream transmission. 16 circular prefix samples are added in front of 64 samples of IFFT output before the transmission. Since the outgoing signal couples to the phone wire through a hybrid transformer, a strong echo signal comes back to the modem receiver. In a FDM system, a sharp low path filter is required to isolate the down-stream signal from the upstream return echo. MDSL uses low cost elliptic analog filter to isolate the downstream and upstream spectrum. This elliptic filter introduces the impulse response longer than 250 μs, which is the period of one DMT frame. It needs a strong TEQ to clean up the inter-symbol interference introduced by the AFE filter. However, since the TEQ in central office modem operates at the low sampling rate, the central office modem can afford a longer tap TEQ. The MDSL DMT also uses a novel training sequence and training algorithm to provide excellent convergence of TEQ on difficult loops.[2]

Typically, a DMT transceiver output has high a peak to average ratio (PAR). Theoretically, for 128 tones of MDSL DMT, the PAR is approximately 24 dB. If the MDSL downstream transmitter transmits at a power density level of -40 dBm/Hz, the 24 dB PAR will result in +/-68 V swing. This requires either a high power transceiver, or the signal has to be clipped at a lower voltage level. Although the clipping is more practically manageable then raising the transceiver power, it will introduce about 10^{-6} bit error rate floor due to the clipping noise. A typical DMT transceiver has to use a deep interleaver and an associated Reed-Solomon code to just remove the DMT self generated clipping errors.

The MDSL DMT uses a clipping mitigation technique to avoid the clipping and consequently saves the requirement on Reed-Solomon decoding. The principle of the clipping mitigation technique is that since the DMT transmitter knows if the outgoing signal clips as early as it performs transmitter IFFT, the DMT transmitter can repair clipping damage when the clipping is detected. Typically, the clipping repairing process needs to change the original signal in a pre-determined sequence. Once transmitter does the clipping repairing, it has to notice the receiver to do the complementary recovery process to bring the original signal back. The clipping mitigation protocol has been built in the MDSL physical layer frame structure.

In a DMT system, the SNR on each sub-carrier may change in time. Also, since during DMT initialization period only a small amount of samples are collected to estimate the channel noise on each sub-carrier, the bits assignments on each sub-carrier may not be adequate. It needs some adjustment on sub-carrier constellation size during the data transmission mode. ADSL suggests bit swap process to accomplish this task. However, it is expensive to support the flexible bit manipulation that bit swap algorithm required in a programmable DSP. Instead, our MDSL DMT uses a "word stuffing" technique to skip the bad sub-carriers.

To efficiently implement a bit-loading algorithm for all the sub-carriers, instead of encoding each frequency sub-carrier individually, the sub-carriers can be grouped and encoded together. Our MDSL DMT uses a 16-bit word unit, and confines the group of sub-carriers to carry one word of total bit length. For example, assuming sub-carrier *i* can support n_i bits, the sub-carriers *i*, *j*, *k* may form a group, if $n_i + n_j + n_k = 16$. There is no sub-carrier carrying the bits for two words in the message bit stream. If one sub-carrier goes bad, only its corresponding word will consistently have errors. However, such errors will consistently constrained inside a well defined word boundary. Therefore, to avoid the errors caused by bad sub-carriers, at the transmitter side, a stuffing word can be placed at the bad locations; and at the receiver side, a complementary word robin process can be used to delete the stuffing word. Since stuffing word is always corrupted by the errors, the modem receiver can not rely on certain flag pattern to recognize the stuffing word. The modem at both ends have to have an agreement in advance before the exercise, and have to synchronize with each other. Such kind of embed operations channel (eoc) is included in the MDSL DMT framing structure.

To locate possible bad sub-carriers, the MDSL DMT uses pre-determined message pattern to monitor the channel performance. The channel monitoring pattern is implemented in the filler message. The filler message is sent when there is no data traffic in the pipe.

Figure 5 shows the MDSL DMT downstream throughput at different loop length.

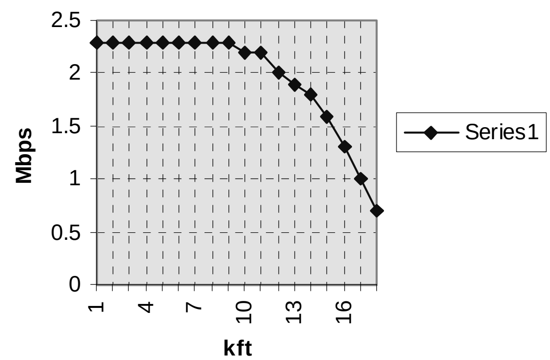

Figure 5. MDSL DMT throughput.

4. Low cost central office modem pool

The low MIPs count of MDSL DMT transceiver gives the advantage that multiple DSL lines can concentrate in a single DSP as shown in Figure 6. As an example of 1600 MIPs TI C6x DSP, 20 DSL lines can be handled simultaneously by single DSP at the central office. Statistically if 20 DSL lines do not run simultaneously the MIPs allocated to one idle line can be borrowed to support another active line. By statistically multiplexing DSP horse power, central office can have higher concentration ratio. Without scarifying QoS (Quality of Service), this statistical DSP horse power allocation should be done on the fly. The switch time between the idle line and the active line should be less than one DMT frame time. Therefore, even the modem is in the idle mode, the central office modem and client modem have to be kept in synchronization. Whenever there is signal for activation, the modem can be warmly started.

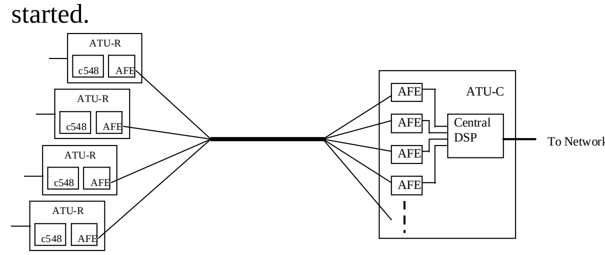

Figure 6 MDSL central office

5. MDSL Modem Internet Access Application

The Internet access application using MDSL modem is deployed using the peer-to-peer connection-oriented WAN model instead of connectionless LAN model. The major reasons are:

1. Under the LAN model most communications must go through a router in the residential site and the router will increase the price of the end equipment.
2. The complexity of the equipment of the LAN model increases and special IP engineering and router management is required.
3. The LAN architecture is not designed for the public networks so the security is not fully guaranteed.

Under the connection-oriented WAN model, the architecture of the residential Internet access through MDSL is described in Figure 7.

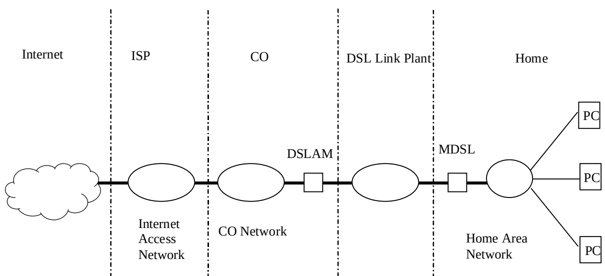

Figure 7 MDSL Home Internet Access Architecture

At the system demonstration stage, a PC running Windows NT 4.0 server that supports multiple MDSL ports replaces the DSLAM system in the central office. Servers in the same LAN as the CO server replace the ISP. An NDIS 4.0 WAN miniport device driver is developed for the MDSL modem to interface the modem hardware and the transport layer protocol drivers under Windows environment. Remote Access Service call manager is used for the client modem to dial in using any phone number of maximum 32 digits and only one call can be active at the same time. The dialing procedure follows Windows Telephony API specifications. The dialing capabilities are implemented using proprietary MDSL link layer messages. After a connection is established the client PC is functioning like connected directly to the LAN where the server PC resides and can share all the resources on the network. For Internet access, the Server PC is functioning as an Internet service gateway. It routes all the IP packets to and from the remote access unit through the Point to Point Protocol (PPP). Figure 8 shows the IP routing implemented under Windows NT 4.0 system.

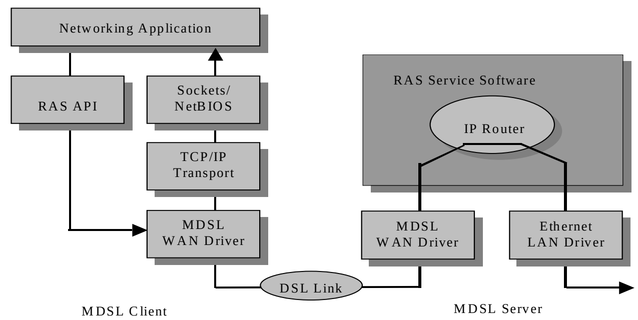

Figure 8. MDSL IP Routing in Windows NT

When MDSL modem runs at the raw bit rate of 1.5 Mbps downstream and 400 Kbps upstream in the above system configuration, the performance of some applications executing under one NetScape 3.1 session is showed in Table 1. The results in table 1 are slightly dependent on the instant LAN traffic at the moment of experiment.

Application	*File Size(KB)*	*Time(s)*	*Data Rate(kbps)*
FTP	8451	61.64	1096(avg.)
JPEG pictures	731	7.35	796 (avg.)
PPT Slides	879	12.42	566 (avg.)
Streaming AVI	21338	N/A	900 (const.)

Table 1. Performance of Intranet Access Applications

The data rate overhead showed above is accumulated when data passing through different layers of the network: application layer, Windows socket API layer, TCP/IP or UDP/IP transport layer, Windows NDIS Wrapper layer, MDSL miniport driver layer, MDSL link layer, etc. Because of the Internet and Intranet traffic the performance difference of using MDSL modem to do Web browsing compared with using Ethernet is very much unnoticeable based on our observation.

Beside Internet and remote LAN access at higher speed MDSL modem is also suitable for other applications such as low speed interactive multimedia services, video conferencing, home shopping and Internet gaming. To add more, MDSL modem will allow the user to receive a telephone call from the same phone line without disturbing all the other activities.

---

[1] “Network and customer installation interfaces - Asymmetric Digital Subscriber Line (ADSL) metallic interface,” ANSI T1.413-1995.
[2] “Low Complexity Time-Domain Equalizer Training For ADSL,” by Song Wu, T1E1.4/96-197.