Chapter2
Very High-Speed Digital Subscriber Lines

In the age of high technology, there is a telephone in virtually every location. The *Digital subscriber line* (DSL) phone line is an attractive choice to transport the data of high speed real time processing systems. Many applications in a telephone and telegraph office, business office, and industrial fields require high bandwidth access. Hence, DSL technology can support high bandwidth information to everywhere needing this bandwidth by using the existing network.

2.1 Different Types of DSL

This subsection gives a brief description about some different types of DSL. *High Data Rate DSL* (HDSL) technology can provide symmetric data rates. It is used for data transmission at 1.544 Mbps and 2.048 Mbps. The basic modulation used by HDSL is 2B1Q.

Asynchronous DSL (ADSL) technology is asymmetric. It transmits different data rates from the central office to the subscriber and vice versa. It allows 1-8Mbps and 100-800Kbps data transmission rates in both directions. ADSL uses the CAP/DMT modulation technique. It can support many applications such as Internet services and video-on-demand (VOD).

Transmission rates of the *Very High Speed DSL* (VDSL) are ten times that of the ADSL. Therefore, VDSL technology is the next generation of wired broadband networks over the ordinary telephone twisted pair. It can support either symmetric or asymmetric data rates. Its data rate is dependent on the actual phone line loop. Just like ADSL, the modulation for VDSL is also CAP/DMT.

2.2 VDSL Network

Standardization of VDSL technology is discussed in committee T1E1.4 of the American National Standards Institute (ANSI) [1]. In Figure 2.1, we can see the schematic diagram of the VDSL network. The main concept of the VDSL network is to transmit data and voice from the central office (CO) to the neighborhood by using a combination of fiber optic cables. VDSL can support frequency separation using Plain Old Telephone Service (POTS) and Integrated Services Digital Network (ISDN). So, it requires an interface device at both ends of the phone line to interface between VDSL and POTS or between VDSL and ISDN. The longest phone lines are approximately 1000 feet to 4000 feet in length from the VDSL transceiver to the CO or ONU. The structure of the VDSL deployment from the central office is called *Fiber to the Exchange* (FTTEx) and the structure of the VDSL deployment from the optical network units (ONUs) is called *Fiber to the Cabinet* (FTTCab).

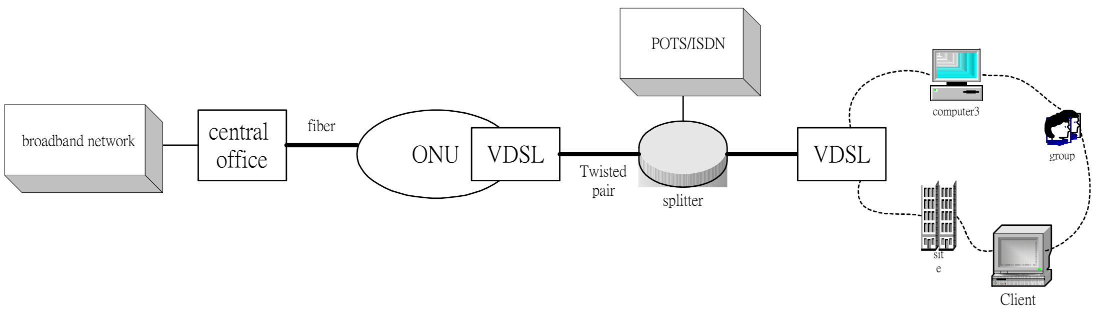

Figure 2.1 The VDSL network

2.3 Effect of Noises for VDSL Transmission

The most common types of noise that can affect the VDSL transmission systems are crosstalk, radio noise and impulse noise[3].

(1) Crosstalk

The phone lines in the central office are bundled together within a single cable bundle. This introduces crosstalk which degrades the VDSL communication performance. Crosstalk is generally caused by either *near-end crosstalk* (NEXT) or *far-end crosstalk* (FEXT), as shown in Figure 2.2. NEXT is interference introduced in a receiver by a transmitter which are both located at the same end of the cable bundle. FEXT is interference in a receiver by a transmitter which are located at the opposite ends of the cable bundle. We can use frequency division duplexing (FDD) to eliminate NEXT, and so FEXT is the only remaining crosstalk problem to interfere with VDSL signals.

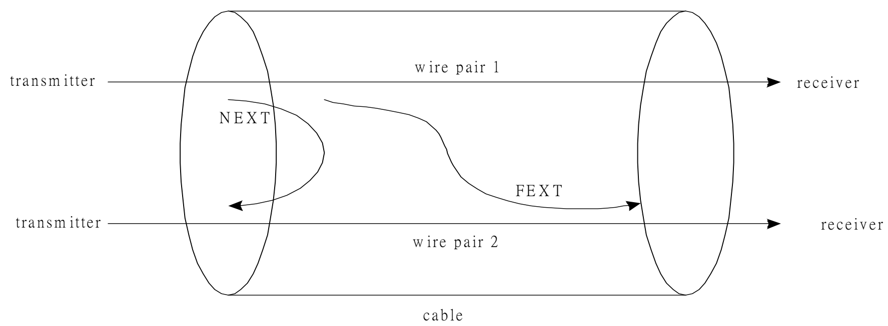

Figure 2.2 Wire pair coupling causing Near End Crosstalk and Far End Crosstalk

(2) Radio Noise

There are two types of radio noise interference. One is broadcast radio frequency interference. The other is amateur radio frequency interference. The former is caused by AM radio noise signals interfering with phone lines carrying VDSL signals. The latter is caused by amateur radio noise signals coupling into VDSL signals.

(3) Impulse Noise

Impulse noise occurs in unshielded twisted pair cables and is caused by various sources such as external circuits or electromagnetic devices.

2.4 DMT Modulation for VDSL

There are currently two types of modulation schemes in VDSL to achieve efficient and reliable data transmission: *Single carrier modulation* and *multicarrier modulation*. Signal carrier modulations are used by Carrierless Amplitude and Phase (CAP) and Quadrature Amplitude Modulation (QAM) techniques. Discrete Multi Tone (DMT) is a multicarrier modulation technique. Here, we discuss only DMT modulation.

DMT divides the incoming data into a number of parallel data structures and then transmits these structures over separate sub-channels [2][22]. The neighboring subcarriers used in DMT are overlapped and orthogonal with each other, as shown in Figure 2.3. DMT modulation schemes used range from BPSK up to 32768-QAM. The typical modulation is 256-QAM [3]. Table 2.1 lists some parameter values of DMT modulation in the VDSL standard [1][2]. The frequency spacing between the subcarriers is 4.3125 kHz. These center frequencies of these carriers are $k\Delta f$, where the interval index k=0,1,2,…,N_x-1. DMT modulating transform defines as follows.

The encoding data will generate N_x complex data values Z_i, where i=0,1,2,…,N_x-1, which includes the zero at DC. However, the zero at DC is not used for data transmission and so DMT transmits only up to N_x-1 subcarriers. The values Z_i can expand to generate $2N_x$ complex values by using Equation (2.1).

$$\begin{aligned} x_i &= Z_i, i = 0, \ldots, N_x - 1 \\ x_i &= conj(Z_{2N_x - i}), i = N_x, \ldots, 2N_x - 1 \end{aligned} \tag{2.1}$$

It transforms the N=$2N_x$ complex frequency domain values x_i to the $2N_x$ real time domain values X_k by using IDFT [1]. This means

$$X_k = \sum_{i=0}^{2N_x - 1} x_i e^{j\frac{2\pi ki}{2N_x}}, k = 0, \ldots, 2N_x - 1 \tag{2.2}$$

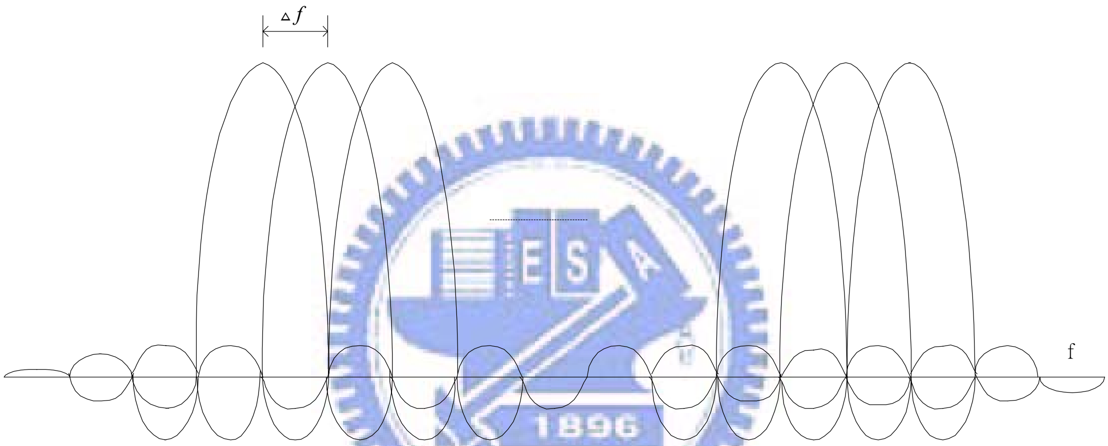

Figure 2.3 Schematic diagram of subcarrier in frequency domain of DMT system

Table 2.1 Parameters of DMT modulation in VDSL standard

Number of subcarriers (N_x)	256,512,1024,2048,4096
Duplexing method	Frequency division duplexing(FDD)
FFT/IFFT size (N)	512,1024,2048,4096,8192
Frequency spacing (Δf)	4.3125kHz
One symbol duration time	231μs
Cyclic prefix length	40, 80, 160, 320, 640

Figure2.4 shows the block diagram of a DMT system [4]. This system uses basic DSP techniques to modulate/demodulate data. Serially transmitted data of up to 4096 subcarriers are modulated into parallel orthogonal data by using IDFT. In practice, it is used by the FFT to implement the DMT system. Before the IDFT output data are sent through the channel, the transmitter should add a cyclic prefix (CP) to eliminate Intersymbol Interference (ISI) and Intercarrier Interference (ICI). The cyclic prefix is removed and is demodulated by an FFT processor at the receiver of the DMT system. The DMT system can express in the mathematical form in Equation 2.3.

$$\begin{aligned} Y_n &= \mathrm{DFT}(\,\mathrm{IDFT}(x_n) \otimes h_n + n_n\,) \\ &= x_n\,\mathrm{DFT}(h_n) + \mathrm{DFT}(n_n\,) \\ &= x_n\,H_n + N_n \end{aligned} \qquad (2.3)$$

$\otimes$: The symbol “cyclic convolution”

Y_n: N- points received data of DMT system

x_n: N-points transmitted data of DMT system

n_n: channel noise

h_n: channel impulse response

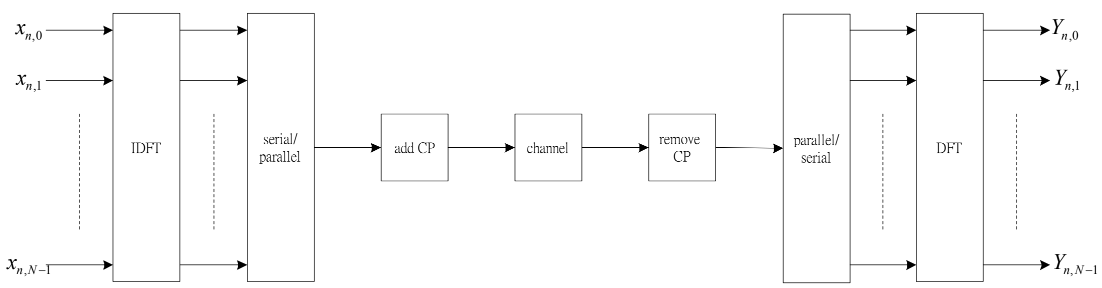

Figure 2.4 Block diagrams of DMT system