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# Research on Access Network Intrusion Detection System Based on DMT Technology

**Lingxi Wu, Jie Zhan, Qiange He, Shuiyan He**
*Hunan University of Science and Technology*, *Xiangtan*, *China*
*E-mail*: *lxwhsy@126.com*
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## Abstract

Analysis is done on the inter-carrier interference (ICI) that caused by multi-carrier communication system frequency offset. The application model of DFT/IDFT in ADSL access network is analyzed further; the hardware detection and software analysis scheme of the system are proposed for the accessing network. Experiments have proved that monitoring system can filter the network data flow and carry on statistical and analysis, achieving real-time monitoring.

**Keywords:** DMT, ICI, Intrusion Detection, DFT/IDFT

## 1. Introduction

The Discrete Multi-Tone DMT () technology has been applied successfully on the ADSL (Asymmetric Digital Subscriber Line) transmission system, and has developed the broadband transmission system that based on Twist-Pair. The problems of network detection and monitoring will be inherent in the development of network, yet the rapid development of the network has been ahead of the real-time monitoring. To solve it, data detection system based on DMT technology has been studied systematically, and data acquisition equipment has been devised, which can achieve filtering analysis and statistics of the network data stream with no influence on the user and the phone company end of the line.

## 2. Multi-carrier Communication System Modeling

QAM (Quadrature Amplitude Modulation) is the basis of DMT, Model use multiple QAM constellation diagram encoders, and each constellation diagram encoder use a different carrier frequency, The DMT code element that were formed by summing all the carries transmitted through the channel. If the receiver can separate sine waves from cosine waves on different frequencies, each wave can be decoded independently, the method of encoded and decoded are consist with the QAM signals; to ensure no interference from $f_l$ to $f_n$ sub-channel, we must make sure that a sine and cosine wave in one sub-channel are orthogonality with any other sub-channels, and its formula is as follow [1,2]:

$$\int_0^T \cos(n\omega t)\cos(m\omega t)dt = 0$$

$$\int_0^T \cos(n\omega t)\sin(m\omega t)dt = 0$$

$$\int_0^T \sin(n\omega t)\sin(m\omega t)dt = 0$$

$n$ and $m$ are unequal integers, and $\omega$ is the base rate.

By the expression of orthogonality, we concluded the each sub-channel frequency must be an integral multiple of base frequency, and the code element period T is reciprocal of the base frequency or an integral multiple of the reciprocal of the base frequency. Two situations would appear: First, the frequency offset is an integral multiple of sub-carrier; second, the frequency offset is not an integral multiple of sub-carriers; both of two situations will make system characteristics deteriorate. Assuming the number of carrier is limited, **Figure 1** is a block diagram of a DMT communication system model [3], and according to the system, we make the following discussion:

During the *'i'* symbol cycle, Assuming the original data symbol is $\{a_{0,i}, a_{1,i}, \ldots, a_{n-1,i}\}$, after IDFT calculate, we can get:

$$b_{k,i} = \frac{1}{N}\sum_{l=0}^{N-1} a_{l,i} \exp\left(\frac{j2\pi lk}{N}\right) \tag{1}$$

Therefore, we can get the output signal x($t$) as follow:

$$\mathrm{x}(t) = \exp(j2\pi f_c t)\sum_{k=0}^{N-1} b_{k,i}\, p\left(t - \frac{kT}{N}\right) \tag{2}$$

 

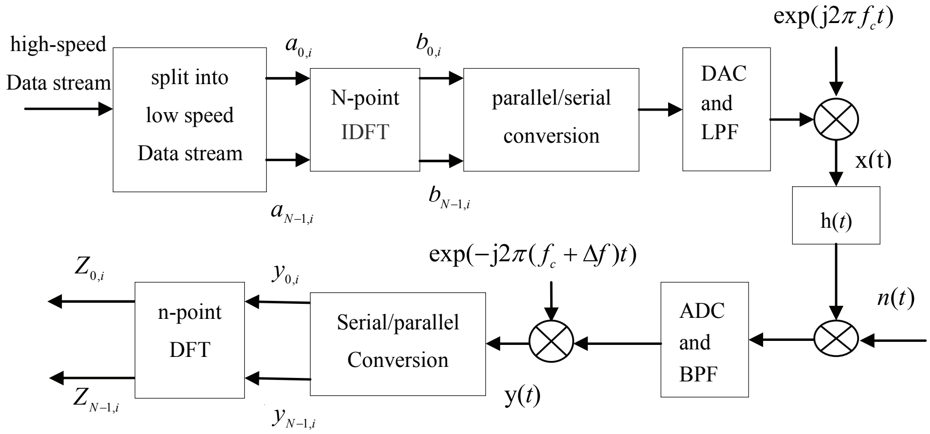


**Figure 1. Multi-carrier communication system modeling.**

$f_c$ represent the carrier frequency, $p(t)$ represent the impulse response of low-pass filter used in the transmitter system, but there is the frequency deviation $\Delta f$ at the receiving end, after down-conversion and low-pass filter the $y(t)$ signal is :

$$y(t)=\exp(j2\pi f_c t+\theta_0)\sum_{k=0}^{N-1} b_{k,i}\,q\left(t-\frac{kT}{N}\right) \quad (3)$$

$q(t)$ represent the combination impulse response get by multiplying low-pass filter of the transmitter and band-pass filter of the receiver, $\theta_0$ is the phase difference between receiver local oscillator and RF carrier. If $q(t)$ can meet the Nyquist criterion at the moment $kT/N$, then we sample $y(t)$ at the same time.

We can get:

$$y_{k,i}=\exp(j\theta_0)b_{k,i}\exp\left(\frac{j2\pi\Delta fkT}{N}\right) \quad (4)$$

According to the DFT formula,

$$Z_{m,i}=\sum_{k=0}^{N-1} y_{k,i}\exp\left(-\frac{j2\pi km}{N}\right),(m=0,1,\ldots,N-1) \quad (5)$$

Substituting (1) and (4) into (5), we can get:

$$Z_{m,i}=\frac{1}{N}\exp(j\theta_0)\sum_{l=0}^{N-1} a_{l,i}\sum_{k=0}^{N-1}\exp\left(\frac{j2\pi k(l-m+\Delta fT)}{N}\right) \quad (6)$$

According to the sum formula $\sum_{k=0}^{N-1} u^k=\frac{1-u^N}{1-u}$, (1-6) can be simplified:

$$Z_{m,i}=\frac{1}{N}\exp(j\theta_0)\sum_{l=0}^{N-1} a_{l,i}\left[\frac{1-\exp\left(j2\pi\left(l-m+\Delta fT\right)\right)}{1-\exp\left(\frac{j2\pi\left(l-m+\Delta fT\right)}{N}\right)}\right] \quad (7)$$

From:

$$\begin{aligned}1-\exp(j2\varphi)&=[\exp(-j\varphi)-\exp(j\varphi)]\exp(j\varphi)\\&=-j2\sin\varphi\exp(j\varphi)\end{aligned} \quad (8)$$

Make: $\varphi_1=\pi\left(l-m+\Delta fT\right)$

$$\varphi_2=\frac{\pi\left(l-m+\Delta fT\right)}{N},$$

(8) can be express as follow:

$$\begin{aligned}Z_{m,i}&=\frac{1}{N}\exp(j\theta_0)\sum_{l=0}^{N-1} a_{l,i}\left(\frac{-j2\sin\varphi_1\exp(j\varphi_1)}{-j2\sin\varphi_2\exp(j\varphi_2)}\right)\\&=\frac{1}{N}\exp(j\theta_0)\sum_{l=0}^{N-1} a_{l,i}\frac{\sin\varphi_1}{\sin\varphi_2}\exp(j(\varphi_1-\varphi_2))\end{aligned}$$

$$Z_{m,i}=\exp(j\theta_0)\sum_{l=0}^{N-1} a_{l,i}c_{l=m} \quad (9)$$

Among of them,

$$c_{l-m}=\frac{1}{N}\frac{\sin(\pi(l-m+\Delta fT))}{\sin(\frac{\pi(l-m+\Delta fT)}{N})}\exp\left(j\pi\frac{(N-1)(l-m+\Delta fT)}{N}\right) \quad (10)$$

$$c_0=\frac{1}{N}\frac{\sin(\pi\Delta fT)}{\sin(\frac{\pi\Delta fT}{N})}\exp\left(j\pi\Delta fT\frac{N-1}{N}\right) \quad (11)$$

$c_0$, $c_1$, ..., $c_{n-1}$ are complex weighting coefficients, corresponding to input data symbols $a_{0,i},a_{1,i},\cdots,a_{n-1,i}$, then we can get the symbols transmitted in $m$th sub-channel as follow ($N$ is the number of coefficients):

$$\begin{aligned}Z_{m,i}&=\exp(j\theta_0)\sum_{l=0}^{N-1} c_{l-m}a_{l,i}\\&=\exp(j\theta_0)c_0a_{m,i}+\exp(j\theta_0)\sum_{\substack{l=0\\l\neq m}}^{N-1} c_{l-m}a_{l,i}\end{aligned} \quad (12)$$

The first item of the formula is data symbol of weighted mathematical expectation, the second item is the ICI caused by $\Delta f$. If $\Delta f = 0$, then $Z_{m,i} = \exp(j\theta_0)\, a_{m,i}$, ($m = 0, 1,\ldots,N-1$). Note: Each complex symbol will be influenced by the phase deviation factor $\theta_0$. If $\Delta f \neq 0$, the inter-channel interference (ICI) will occur. **Figure 2** shows the relationship between the real part, imaginary part, modulus of the complex weighting coefficient and the sub-carrier number $N$ in case of the two kinds of $\Delta f\, T$. When the frequency deviation increases, the stable zone quickly narrows, the modulus value rapidly increases, indicating ICI increases significantly

## 3. ADSL System Based on Multi-carrier Technology

According to the model [3,4], assume $T$ is the cycle, we derive the waveform expression that added up sine and cosine waves :

$$S(t) = \begin{cases} X_n \cos(n\omega t) + Y_n \sin(n\omega t) & 0 \le t \le T \\ 0 & else \end{cases} \quad (13)$$

The waveform shows the influence that a single subchannel $n$ operate on DMT code element, according to Nyquist theorem, sampling the signal, sampling frequency is $2Nf$, sampling value is:

$$\begin{aligned} S_K &= X_n \cos(n\omega \frac{k}{2Nf}) + Y_n \sin(n\omega \frac{k}{2Nf}) \\ &= X_n \cos(\frac{\pi nk}{N}) + Y_n \sin(\frac{\pi nk}{N}) \qquad 0 \le k \le 2N-1 \end{aligned} \quad (14)$$

Make the Discrete Fourier Transform (DFT) to these $2N$ points as follow:

$$\begin{aligned} S_m &= \sum_{k=0}^{2N-1} \left[ X_n \cos(\frac{\pi nk}{N}) + Y_n \sin(\frac{\pi nk}{N}) \right] e^{-j2\pi mk/2N} \\ &= \sum_{k=0}^{2N-1} \left[ X_n \frac{e^{jn\pi k/N} + e^{-jn\pi k/N}}{2} + Y_n \frac{e^{jn\pi k/N} - e^{-jn\pi k/N}}{2j} \right] \\ & e^{-j\pi mk/N} \\ &= \begin{cases} N(X_n - jY_n) & m = n \\ N(X_n + jY_n) & m = 2N\text{-}n \\ 0 & else \end{cases} \end{aligned}$$

(15)

From (14) and (15), we conclude that the output can be mapped to a complex number by making DFT to the signal, the value of encoder X-axis (cosine amplitude) represents the real part of the complex number, the value of Y-axis (sine amplitude) represents the imaginary part of the complex number, then it is a way to generate DMT code element. If make Inverse Fourier transform to $S_m$, we can deduce $S_k$:

$$\begin{aligned} S_K &= \frac{1}{2N} \sum_{m=0}^{2N-1} S_m e^{j2\pi mk/2N} \\ &= \frac{1}{2}\left[ (X_n - jY_n) e^{j\pi mk/N} + (X_n + jY_n) e^{j\pi(2N-n)k/N} \right] \\ &= \frac{1}{2}\Big[ (X_n - jY_n)(\cos(\frac{\pi nk}{N}) + j\sin(\frac{\pi nk}{N})) \\ &\quad + (X_n + jY_n)(\cos(\frac{\pi nk}{N}) - j\sin(\frac{\pi nk}{N})) \Big] \\ &= X_n \cos(\frac{\pi nk}{N}) + Y_n \sin(\frac{\pi nk}{N}) \qquad 0 \le k \le 2N-1 \end{aligned}$$

(16)

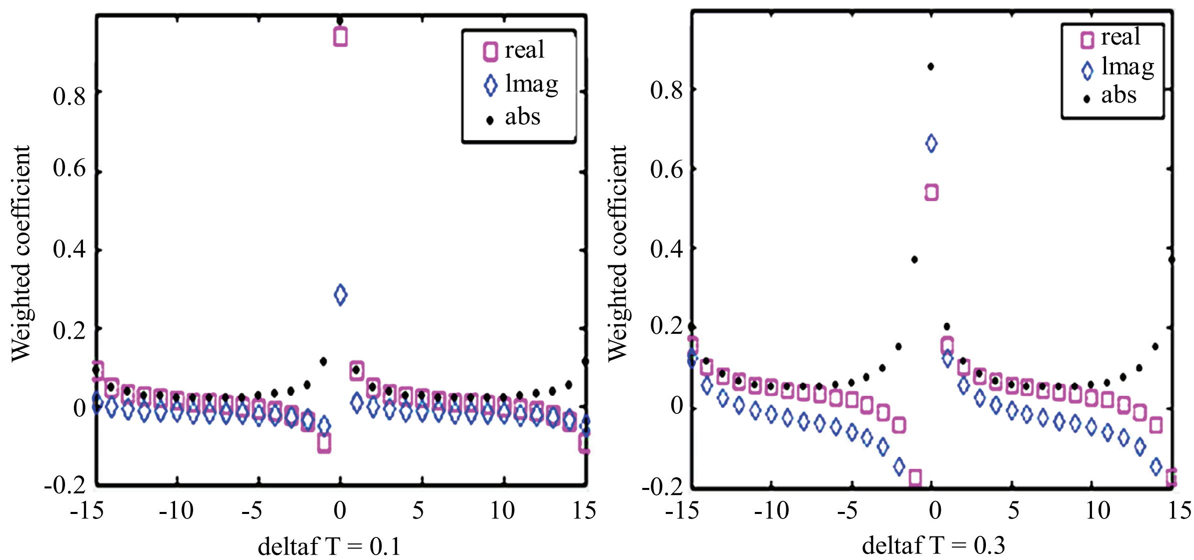


**Figure 2. Carrier frequency deviation and synchronization features.**

The DMT modem can be achieved with DFT and IDFT. From (13) it can be derived the complex number $N(X_n - jY_n)$ to the $n$ th sub-channel, express that a complex number can represents a sub-channel of DMT, $N$ sub-channels have $N$ complex numbers, plus $N$ conjugate complex numbers $(X_n + jY_n)$, we can get $2N$ complex numbers, from (14) ,we can get $S_k$ through making IDFT to $2N$ complex numbers. So we can get DMT modulation, demodulation program, this program has been applied to ADSL modem. In the ADSL, ATU-C downstream modulator uses 256 windows, which is 256 complex numbers, the interval of windows is 4.1325 kHz. Frequency range is from 4.3125 kHz to 1.104 MHz, according to code analysis, the IDFT of downstream DMT can be expressed as:

$$S_K = \sum_{m=0}^{511} S_m e^{j\pi mk/256}, \; k = 0,\ldots,511 \quad (17)$$

$S_m$ is the complex number value or expanded conjugate complex number made by QAM constellation encoding for each sub-carrier, $S_k$ is the time-domain sample sequence after DMT modulation, and the time-domain waveform can be generated after parallel-serial conversion and DAC.

The upstream DMT modulation of ATU-R uses 32 windows, 32 complex numbers represent the coding results of each sub-channel constellation, the audio interval is 4.3125 kHz, frequency range from 4.3125 kHz to 138 kHz. According to the code analysis that the DMT of IDFT in the upstream can be expressed as:

$$S_K = \sum_{m=0}^{63} S_m e^{j\pi mk/64}, \; k = 0,\ldots,63 \quad (18)$$

## 4. Research on Intrusion Detection System

The principle is shown in **Figure 3**. The structure of collector mainly consists of the DSLAM Simulation Module [5-7], Modem Simulation Module and Data Interface Module and so on. The end of ADSL Modem accesses to the DSLAM simulation module of data acquisition equipment, the end of Telecommunications Bureau accesses to the ADSL Modem Simulation Module of data acquisition. After the upstream signals input DSLAM

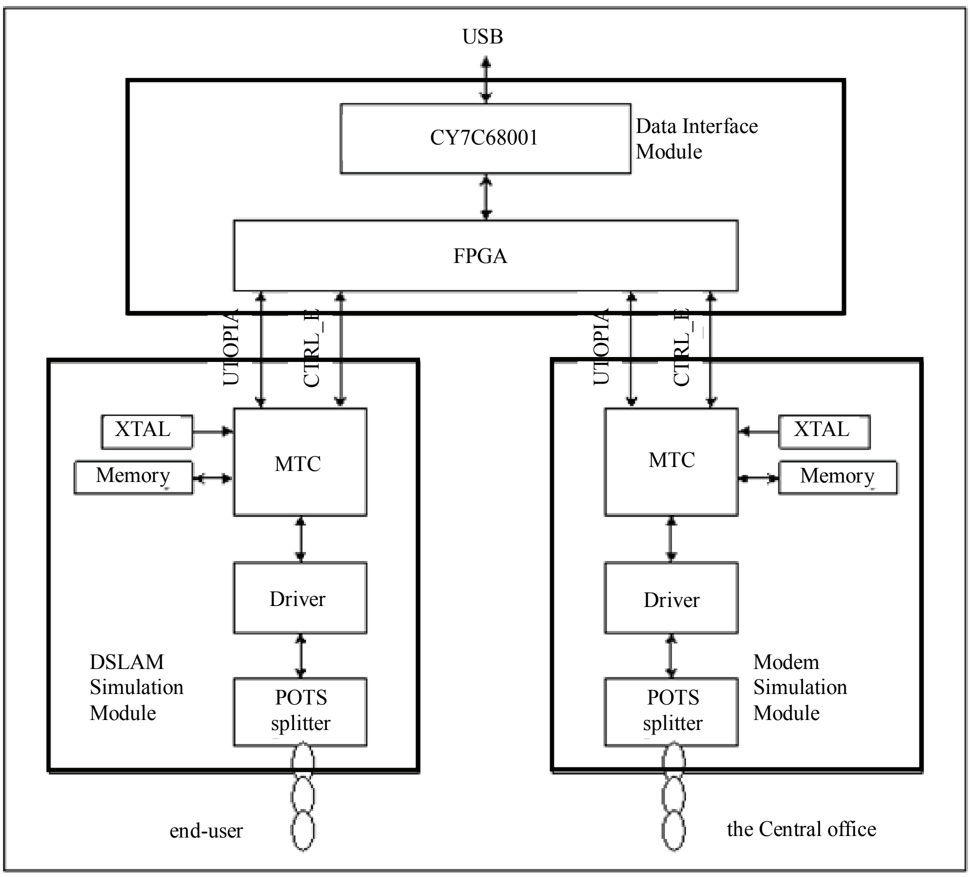


**Figure 3. Hardware block diagram of data acquisition system.**

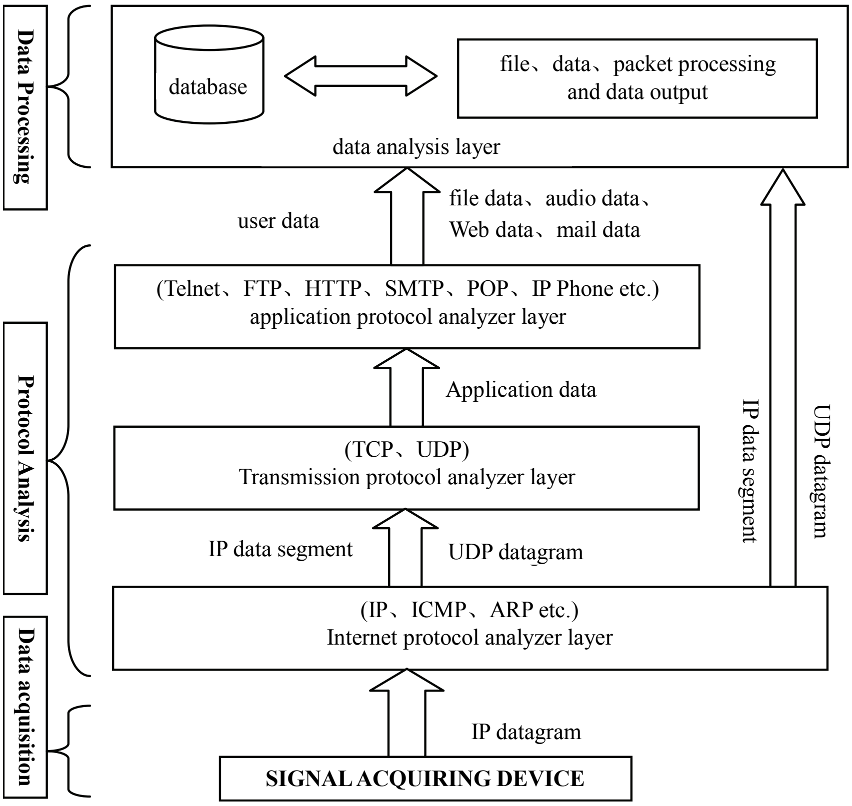


**Figure 4. System software descriptions.**

simulation module, we complete DMT demodulation and send the demodulated signal to the interface module, then send to the computer by USB interface. Meanwhile, the upstream signal is also sent to the ADSL Modem Simulation Module, complete the transmission of upstream data to Telecommunications Bureau. After downstream signals input the ADSL Modem Simulation Module, we complete DMT demodulation and send the demodulated signal to the interface module, and then send to the computer through USB interface. Downstream signal is also sent to DSLAM Simulation Module, and complete the transmission of downstream signal to the user. The normal signals of consumer are connected directly with the dedicated POTS access between the two simulation modules. So, the device joined Telecommunications Bureau and user ADSL Modem, it will not affect the user's normal voice and data communications, both of them are not aware of the existence of the device. Through the UTOPIA interface [8,9], we extract the cell, and encapsulate the cell to get USB packets, and transmit to the computer through the USB interface to analyses the data, the process includes two parts (data processing and protocol analyzer), in order to restore the data effectively and accurately from the obtained data, we must make out the software , according to the system request the software hierarchy is shown in **Figure 4**.

## 5. Conclusions

The distance of data transmission on the Twist-Pair is limited, and the variety of circuit characteristics will affect the status of circuit connection which may cause normal users can't explore the Internet, Meanwhile network data transferring is bidirectional and the upstream and downstream data transferring are asymmetry that makes a great deal of difference from other wired or wireless audio and video signal transmission. In this paper, the data acquisition system is a data receiving system. In process of the upstream and downstream data processing, there are several technical difficulties in data extraction, separation, storage, etc, and our program can solve these problems well. It brings new solutions to the data acquisition system for detecting network data transmission and eliminating network failure, particularly it can solve the problems of monitoring the real-time.

## 6. Acknowledgements

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