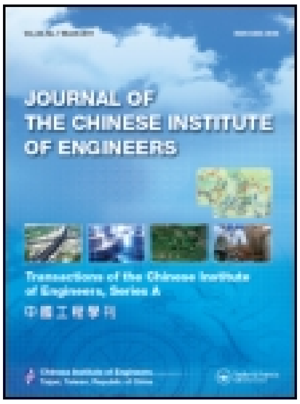

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Throughput performance of DMT-based VDSL system at high sampling rates

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Short Paper

THROUGHPUT PERFORMANCE OF DMT-BASED VDSL SYSTEM AT HIGH SAMPLING RATES

Sun-Ting Lin* and Che-Ho Wei

ABSTRACT

Very high-speed digital subscriber line (VDSL) is a cost effective solution for the last mile of the network over the existing twisted-pair telephone lines. The target of the VDSL system is to raise the transmission data rate up to 52 Mbps for short distances (300 m or less). This paper investigates the throughput of a DMT-based VDSL system at high sampling rates under the influence of various noises/interferences. The throughput limitation of the VDSL system is discussed and the optimal solutions of the sampling rates under various test loop lengths and environmental conditions are also investigated.

Key Words: cyclic prefix reconstruction, intersymbol interference (ISI), discrete multitone (DMT), very high-speed DSL (VDSL).

I. INTRODUCTION

Discrete multitone (DMT) modulation is a technique in which a transmission channel is partitioned into a number of independent, parallel sub-channels, and each of them carries a lower-speed quadrature amplitude modulated (QAM) signal, as discussed by Chen (1998) and Cioffi (1997). The modulation scheme is now widely used in the DMT-based asymmetric digital subscriber line (ADSL), which can be referred to the ANSI standard T1.413 (1997). Due to the increased presence of optic fiber in the telecommunication network, the last mile of a twisted-pair line has been gradually reduced, to below 1.5 Km, especially in urban areas. The available frequency spectrum of these short copper wires for transmission becomes much broader and its channel capacity grows dramatically. A new service called very high-speed DSL (VDSL), which is G.993.1 (2004), can provide up to 52 Mbps or even more over a short telephone line to meet broadband access-network requirements. VDSL can be regarded as an evolution of the ADSL system, and several VDSL system architectures have been proposed, for example, Cioffi (1998), Lin and Wei (2001), Chang *et al*. (2002), and Nava and Del-Toso (2002), etc. These systems use the entire frequency band from a few hundred kHz to beyond 10 MHz over loops using various types of technology.

Previously, Lin and Wei (2001) proposed an asymmetric VDSL system, upgraded from a DMT-based ADSL system by multiplying the symbol rate. Its architecture and symbol format are the same as the original ADSL system except that both clock rate and frequency bandwidth are increased in the same ratio. At that time, the DMT technology was not as popular as today and there were many other candidate technologies for the VDSL system, however, it has become the most popular technology, currently. In this paper, the throughput performance of this proposed system is analyzed over VDSL test loops at various sampling rates because there are shortages of these types of throughput performance analysis for the DMT VDSL system. This throughput has its upper limitation due to the characteristics of the twisted-pair channel. In addition, some noise types such as

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next-end crosstalk (NEXT), far-end crosstalk (FEXT) and other background noises, which lower the throughput of the system, are taken into consideration in the analysis. Recently, there have been studies to discuss the cancellation of FEXT noise, such as Leshem and Youming (2004), however, more types of interferences are discussed in our paper.

II. PROPOSED VDSL SYSTEM DESCRIPTIONS

In this section, the VDSL system described in this paper has the same architecture as the ADSL system discussed by Lin and Wei (2001), as shown in Fig. 1. All the functional blocks in Fig. 1 are built for computer simulations by using MATLAB. The basic DMT-based ADSL transceiver system includes 512-point FFT, and its symbol rate is 4 kHz on the downstream side. If the cyclic prefix length is 32, this DMT system includes 256 sub-channels, at bandwidths of 4.3125 kHz each, for data carrying and other overheads such as cyclic prefixes or synchronization symbols. Since the maximum throughput supported by this transmission system depends on the characteristics of the channel, the channel modeling and bit-loading of each sub-channel must be computed first. After these calculations are performed, the throughput of this DMT system is determined by the product of the symbol rate multiplying the total bit-loading summation in a symbol.

The throughput supported by this system depends on the channel characteristics and the bandwidth used. For example, if the FFT size is fixed and the symbol rate is doubled, the bandwidth of each sub-channel should be increased to 8.625 kHz, which is twice the original system configuration. Therefore, the total bandwidth used is doubled. Otherwise, if the bandwidth of each sub-channel is fixed as 4.3125 kHz, then the FFT size must be increased to enlarge the system throughput.

III. INFLUENCE OF NOISES/INTERFERENCES ON THE THROUGHPUT

In this section, some computer simulations are used to analyze the relationship between throughput performance and sampling rate. From these results, it can be seen that the throughput of a DMT-based VDSL system depends on the test loop length and sampling rate as well as working environment.

The curve of throughput performance and sampling rate can be divided into two parts: linear region and saturation region. In the linear region, the throughput increases with the sampling rate, while in the saturation region, the throughput remains nearly flat. In general, the transition point from the linear

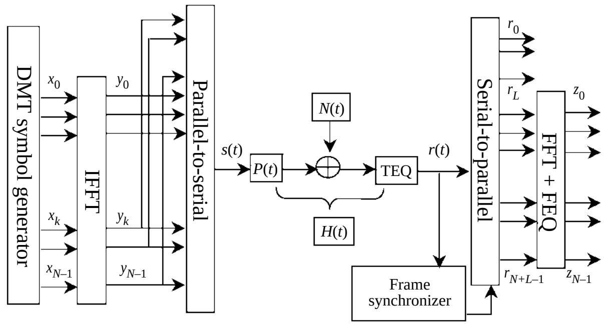

Fig. 1 Block diagram of VDSL system

region into the saturation region depends on the loop length. As the test loop gets longer, the throughput of the DMT-based VDSL system becomes smaller and the saturation point occurs at a lower sampling rate. We can see that the throughput also depends on the SNR and channel characteristics, such as bridged taps and noise/ interference sources like AWGN, ADSL NEXT, VDSL FEXT, etc.

1. AWGN vs. Crosstalk

In ITU-T G.996.1 (2001), many crosstalk interferences are included in the test procedure for DSL transceivers. Here, different crosstalk interferences, such as HDSL, ADSL NEXT and VDSL FEXT, etc. are selected to simulate their influences on the system throughput. In general, NEXT interference is much larger than FEXT for the same type of signals, therefore, the NEXTs from other DSL systems play a dominant role for system throughput if they coexist. The first case simulated is studying the influence of the HDSL system. The power spectrum of the HDSL signal is concentrated below 700 kHz. Doubling the sampling rate of the VDSL system, with bandwidths about 4.4 MHz, the effect of the HDSL system is then insignificant, with degradation less than 5%. The T1 NEXT, with stronger power spectral density and broader bandwidth has more effects on the system throughput. The ADSL system with bandwidth of 2.208 MHz has similar effects on VDSL performance. In Fig. 2, the effects of various crosstalk interferences are displayed by plotting, together with the original AWGN corrupted signal, at test loop length 300 m and length 600 m.

In examining the self-crosstalk interferences, the NEXT problem can be discarded and only the FEXT of the VDSL system should be considered. It is clear that this FEXT depends on the loop length. The shorter the loop is, the larger the degradation will be, as also shown in Fig. 2 The formulas used in the above simulations refer to the ITU-T standard G.996.1 (2001). From those formulas, it can be observed that the amount of induced FEXT depends on the loop length while

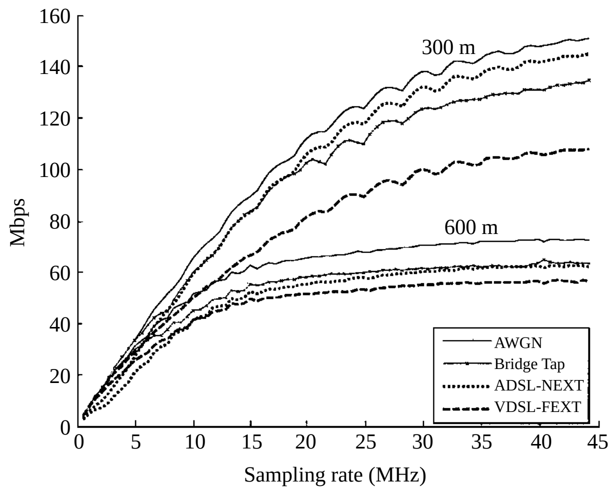

Fig. 2 Throughput comparison of the tested loops in various environments

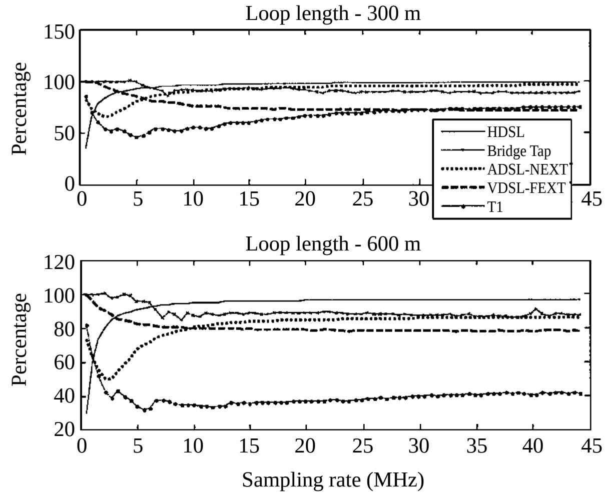

Fig. 3 Throughput percentage comparison of various noises over AWGN

that of NEXT does not. Our simulation results indicate this phenomenon. These results are reasonable because the coupling of the interference from the far-end will decay more through the longer loop.

2. AWGN vs. Bridged Taps

It has been observed that bridged taps can cause notches in the frequency response of VDSL loops. If some bridged taps of various lengths are added into the middle of a test loop, the shortest bridged tap will cause the deepest null as described by Wang *et al*. (1999) and Im (2002). In our test case, we use the simple bridged tap configuration with both vertical and horizontal sections being 15.2 m each. The simulation results are also shown in Fig. 2.

For the bridged taps located at the same distance from the end point of the test loops, it can be observed from the simulation curves that the influence of the bridged taps depends on the sampling rate as well as the loop length. In the lower sampling rate case, the bandwidth used does not cover the notch caused by the bridged taps; therefore, the power spectra of these two test loops, with or without bridged taps, are approximately the same. In contrast, if the used bandwidth covers one notch or more, the bit-loading number under those certain frequency band decrease toward zero. Thus, the throughput of the whole system is degraded. The ratio of the degradation depends on the width, depth and number of notches covered.

IV. ANALYSIS OF THROUGHPUT PERFORMANCE

In Fig. 3, the percentages of the channel capacities under various interference effects to the AWGN-only case are plotted. From the simulation results, T1 NEXT degrades the system throughput seriously. Since the T1 system is the first generation digital carrier, it does not consider spectral compatibility with other DSL systems. Therefore, it is very noisy when combined with a new DSL system. For example, the shaping filter of the T1 system is not so sharp that its sidelobe signal induces severe interference in other systems. In the real world, the single-pair high-speed digital subscriber line (SHDSL: a modulation scheme for repeater-less T1 service) is replacing T1 service in main lines, therefore, the influence of the T1 system can be avoided.

The influence of the HDSL NEXT on the VDSL system is small, especially in a high sampling rate system. The ratio of system throughput reaches above 90%, even to 95% under this NEXT influence while the sampling rate is above 5.5 MHz.

The notches caused by the bridged taps will lower the system throughput if the used band covers these notches. From our simulation, the effect of the bridged taps causes about 10% to 15% penalty to the whole system throughput at high sampling rate, as shown in Fig. 3. It can be seen that if the sampling rate is below 5.5 MHz, the system throughput under the influence of one short bridged tap (15.2 m) can be ignored.

The influence of ADSL NEXT is concentrated at low sampling rate, especially below 2.2 MHz since the shaping filter of an ADSL system is sharp enough to cut its power spectral density under -140 dBm/Hz if the bandwidth is above 2.2 MHz. The throughput degradation caused by the ADSL system is about 10 to 20 percent while the sampling rate is above 11 MHz. From Fig. 3, it can be seen that other VDSL systems induce a large amount of crosstalk especially for a short loop case. The degradation can be more

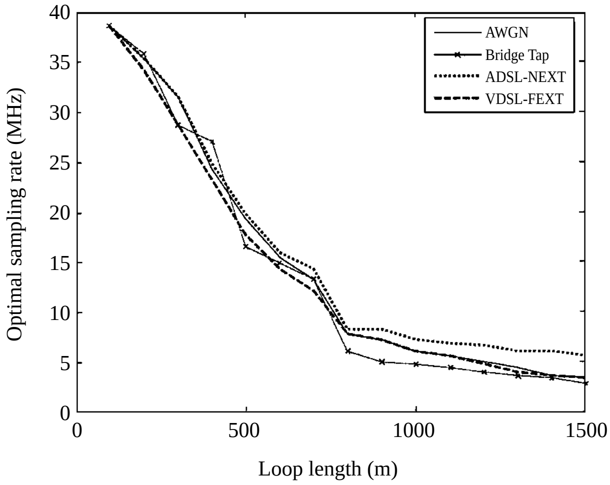

Fig. 4 Optimal sampling rate and throughput of various DMT VDSL test loops

Table 1 Optimal throughput of various DMT VDSL test loops (Mbps)

Length (m)	AWGN	BT	ADSL	VDSL
100	227.41	213.37	223.28	155.34
200	179.73	164.61	174.64	124.62
300	137.49	124.08	131.37	98.86
400	103.97	92.12	96.68	79.03
500	78.83	68.82	70.33	62.61
600	61.72	54.63	52.50	51.11
700	50.17	43.26	40.48	42.96
800	28.32	28.25	17.85	28.01
900	24.03	24.47	13.46	23.70
1000	19.78	19.82	9.20	19.50
1100	17.42	16.91	6.89	17.19
1200	15.23	14.26	4.90	15.06
1300	13.04	12.45	2.96	12.91
1400	11.63	11.43	2.49	11.53
1500	10.10	10.37	2.06	10.03

than 30 percent if the test loop is 300 m long.

From the simulations, it is observed that, although many effects lower the throughput of a DMT-based VDSL system, the throughput can be increased with the sampling rate until reaching the saturation point. The optimal sampling rate of the system is selected by finding the minimum sampling rate of a test loop with throughput up to 90 percent of its optimal value. The influence of an HDSL system is small and can be ignored. The influence of a T1 system on a VDSL system is so significant that it is not practical to bundle these two types of service together.

From the simulations, if the loop length is below 800 m, increasing the sampling rate will improve the system throughput significantly. The optimal sampling rate for the VDSL system varies from 5.5 to 40 MHz if the loop length is below 800 m, as shown in Fig. 4. Otherwise, for loop length above 800 m, 4.4 MHz sampling rate is good enough to reach the optimal throughput of a DMT-based xDSL system. The optimal throughput of the DMT-based VDSL system also depends on the loop length. From the simulation results, the throughput, including both upstream and downstream, can reach above 50 Mbps only if the loop is shorter than 600 m, as shown in Table 1.

From Table 1, it can be seen that the influence of ADSL NEXT is very significant for a long loop, especially one longer than 800 m; while the influence of VDSL FEXT is substantial for short loops.

V. CONCLUSIONS

The throughput performance of a DMT-based VDSL system under various constraints, such as the effects of crosstalk and bridged taps, is analyzed. It is observed that raising the sampling rate can improve the system throughput, especially when the loop length is short. However, this method has its limitations as shown in the previous simulations, and the optimal solutions are calculated according to the defined constraints. From our simulation results, if the loop length is below 800 m, increasing the sampling rate will improve the system throughput significantly. Otherwise, for loops with lengths from 800 m to 1500 m, a 4.4 MHz sampling rate is good enough to reach the optimal throughput of the DMT-based VDSL system.

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