Using Time-Spreading to Combat Multi-user Interference in ADSL and VDSL Systems

J.H. van Wyk and L.P. Linde

Abstract—Asymmetric Digital Subscriber Line (ADSL) is a high-speed wireline access technology capable of supporting up to 8 Mbps downstream and 1 Mbps upstream in a bandwidth of 1.1 MHz. ADSL uses Discrete Multi-tone (DMT) modulation, allowing it to optimally adapt to changing line conditions, including line length, line topology and interference. Various techniques, like Reed-Solomon coding, time equalizers, frequency equalizers and cyclic prefixing are used to combat the effect of interference in the system. These methods are limited in their ability to completely remove interference.

In this paper we propose a time-spreading (TS) technique, using complex spreading codes. The technique is capable of rebuilding the signal, under severe multi-user interference and fading channel conditions. The technique only requires the addition of time-spreading/despreading modules between the transmitter and receiver in order to function. It can also be used on other xDSL related systems, such as Very-high-bit-rate DSL (VDSL).

Keywords—Time-spreading (TS), Asymmetric Digital Subscriber Line (ADSL), Discrete Multitone (DMT), multi-user interference cancellation

I. INTRODUCTION

ADSL is the acronym for Asymmetric Digital Subscriber Line, a local loop transmission access technology. ADSL is part of the xDSL family, used mainly to provide high data rates over a twisted-pair channel. xDSL is considered as a transition technology towards an all-fiber network, commonly known as fiber-to-the-home (FTTH). ADSL is asymmetric because downstream (towards the customer) the data rate is higher than the upstream (towards the network) data rate. This has great benefits when compared with symmetric systems, in terms of higher downstream data rates and longer lines (extended reach) by reducing the near-end crosstalk (NEXT) between ADSLs [1, 2].

Although ADSL implements advanced interference cancellation techniques, such as Reed-Solomon forward error correction (RS-FEC) coding, interleaving, Viterbi decoding and cyclic prefixing, the effect of other users are still visible. This can be deduced from the fact that the data rate of a specific user decreases as the number of simultaneous users on the same cable increase. This is all due to interference resulting from crosstalk.

In this paper we propose a time-spreading (TS) technique to effectively combat the effect of multi-user interference. It only requires the addition of time-spreading/despreading modules to the transmitter and receiver in order to function.

The basic operation of a ADSL modem is provided in Section II. The operation of the time spreading/despreading modules are provided in Section III. The simulation results are provided in Section IV, followed by a discussion in Section V.

II. DMT OPERATION

The modulation used by ADSL is Discrete Multi-Tone (DMT) [1–4]. DMT divides the entire bandwidth range (0 to 1.1 MHz) into 256 equally spaced subchannels (also called tones), each occupying 4.3125 kHz. Subchannels #1 through #6 are reserved for the 4 kHz passband analog voice plus a wide guard-band. Subchannel #64 (276 kHz) is reserved for a pilot signal [1, 5–7]. There are 26 upstream channels, starting at subchannel #7, 250 downstream channels when echo cancellation are used and 224 when FDM is used [2] (generally preferred over ECH). When the ADSL modem is activated, a complex handshaking procedure measures the gain (by sending unit energy in each subchannel) and noise present in each subchannel. These measurements are used to optimally adjust the spectral efficiency (measured in terms of bits/symbol/Hz) for each subchannel, up to 15 bits/symbol/Hz [1, 6]. The appropriate combination of energy and number of bits to be carried on each tone is then determined based on the desired detection symbol error probability [8].

Each transmission line can be represented by a corresponding signal-to-noise ratio (SNR) profile. A water-filling bit-loading algorithm similar to that of Campello [9] is used to obtain the allocated bits per tone. For this simulation a practical 4 km local loop, as shown in Fig. 1, will be used. The DMT transmitter is shown in Fig. 2.

The serial-to-parallel converter converts the incoming serial bit stream into parallel data which is grouped in blocks. The block size is a function of the number of subchannels used, as well as the number of bits allocated to each subchannel. The block size is not fixed, due to the rate adaptable feature of DMT. After bit loading, the constellation encoder maps the designated number of bits into a unique complex symbol for every subchannel. These symbols are then scaled to obtain the same average power for each tone – this gives DMT systems their characteristic flat spectrum.

In the DMT system, modulation is performed by a 2N-point IFFT, transferring the parallel independent subchannels in the frequency domain to the time domain. When the DMT system is implemented on ASIC, all values should be real (instead of imaginary). To assure that the IFFT at the DMT transmitter side (ATU-C) generates only real-valued outputs, the inputs of the IFFT...
have the following constraints [10], based on Hermitian symmetry:

\[ x(n) = x^*(2N - n) \quad \text{for} \quad n = 0, 1, \ldots, N - 1 \]  
\[ x(0) = x(N) = 0 \]  

where \( N = 256 \), \( x(n) = x_r(n) + jx_i(n) \) are the input encoded complex symbols and \( x^*(\cdot) \) is the complex conjugate of the encoded complex symbol for subchannel \( n \).

The DMT receiver is shown in Fig. 3. The \( 2N \) real values are inputs to a FFT to convert it back to the original \( N \) complex symbols by using only the \( N \) subchannels at the top. The constellation decoder converts the complex symbol back to bits.

### III. Time spreading/despreading

Time spreading (TS) is a time diversity technique, with the following characteristics [11, 12]:

- TS is simple to implement
- TS does not drastically affect the modulation spectrum (modulation bandwidth) of the current system
- TS can be used in conjunction with existing error-correction techniques, since it is intended to supplement such techniques, and not compete with, or replace them.

Unlike interleaving, which spreads bits in time, with a reduction in the rate at which bits can be sent, Time Spreading does not change the bitrate. This is made possible by allowing the spread bits (of a spreading sequence) to overlap in time. A schematic representation of Time Spreading is shown in Fig. 4 [11–13]. In general,
P a r a l l e l
to  S e r i a l
C o n v e r t e r
S e r i a l D a t a  o u t
C o n s t e l l a t i o n
D e c o d e r
N
F F ... v e r t e r
2 N
A D C
&
A n a l o g
C i r c u i t r y
R e c e i v e d
s i g n a l
I g n o r e  c o m p l e x  s y m b o l s

Fig. 3. Simplified DMT Receiver

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Fig. 4. Theoretical QPSK (reference)
ADSL system (0.4mm 4km local loop)
with TS
with TS and 100 user noise
with TS and 1000 user noise

Fig. 5. The time-spreading module is implemented as

by:

\[ y_k = \begin{cases} 
\sum_{i=0}^{n} b_{k-i} c_i & ; k < L \\
\sum_{i=0}^{L-1} b_{k-i} c_i & ; n \geq L 
\end{cases} \quad (3) \]

The complete system, incorporating the time spreading/despreading modules, are implemented as shown in

Fig. 4. Theoretical QPSK (reference)
ADSL system (0.4mm 4km local loop)
with TS
with TS and 100 user noise
with TS and 1000 user noise

Fig. 5. The time-spreading module is implemented as

shown in Fig. 6, according to Fig. 4 and Eq. (3). At the receiver side, the received signal is correlated with the real and imaginary parts of the spreading code.

IV. Results

The results obtained are shown in Fig. 7. QPSK is used as a reference. Time Spreading was added to observe its effect. To simulate a multi-user environment in order to see if Time Spreading can be used, 100 and 1000 users were added as noise in the system. The Eb/No ratio for the DMT system must be higher as for the same corresponding bit error rate (BER) on the QPSK graph. This is due to the 'average' constellation which is obtained for the complete ADSL system, which uses different constellations in each subchannel. The results also shows the effect of adding Time Spreading to the system. Due to the spreading of each data point over the whole channel bandwidth, the effect of AWGN fading is reduced. When adding the noise, as generated by 100 and 1000 users respectively, the BER degrades. Time Spreading however has a characteristic noise floor (as observed from 25dB
V. Conclusion

Time Spreading generates internal self-noise [12], a problem that needs further research. The level at which this floor occurs is a function of the sequence length. However, increasing the sequence length leads to increased time-delay and processing in the system. Thus we have a trade-off between reliable transfer (which can be improved by using error-correction techniques) and using Time Spreading to combat multi-user interference. It should be noted that for a ADSL system employing all Forward Error correction coding, equalizers etc., the vit error rate performance will be better. A simple system was used to illustrate the operation of Time-spreading. In conclusion, Time Spreading can be used as a method to combat multi-user interference in ADSL, as well as other systems.

References


Jacques H. van Wyk holds a B.Eng(1997) degree and a M.Eng(1999) degree (with specialization in xDSL technology) from the University of Pretoria. He is currently busy with a PhD degree at the University of Pretoria, looking into methods to improve performance and mitigate multiuser interference in ADSL and VDSL systems. He was an employee of Telkom SA Ltd. from 1996 - 2002. He is currently a senior lecturer in the Department of Electrical, Electronic and Computer Engineering at the University of Pretoria and vice-director of the Telkom COE in Teletraffic Engineering (CeTEIS).

Louis P. Linde holds a Hons-BEng(1973) degree in Electrotechnical Engineering from the University of Stellenbosch and M.Eng (1980) and D.Eng (1983) degrees in Electronic Engineering from the University of Pretoria. He is presently the Group Head of Signal Processing and Telecommunications in the Department of Electrical, Electronic and Computer Engineering (E,E&C Eng), University of Pretoria, as well as Director of both the Centre for Radio and Digital Communication (CRDC) and the DigiMod Group.