# Computational Reduction During Idle Transmission in DSL Modems

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# ABSTRACT

This document describes two methods for reducing computational requirements during idle transmission in remote access systems incorporating digital subscriber line (DSL) modems, including asymmetrical DSL (ADSL) systems. These methods save processing power during idle transmission by generating an idle signal using lowcomplexity techniques. The generated idle signal is made spectrally compatible with xDSL systems and a nondisruptive signaling scheme is used to indicate to the farend receiver the transition between idle to active or active to idle status. A technique is presented that modulates the phase of the pilot tone to signal status transitions to the remote receiver. The computational complexity at the receiver is reduced because full demodulation and decoding is not required to determine that an idle signal is being transmitted.

# 1. INTRODUCTION

Asymmetric digital subscriber line (ADSL) modems transmit high rate digital data over the existing twisted pair telephone line to connect residential customers to a digital network. Discrete multi-tone (DMT) is a multicarrier modulation technique used in xDSL systems for transmitting high-speed data in the presence of significant inter-symbol interference. ADSL is well suited for applications in which the data rate needed in both directions is not the same. Such an application is Internet access.

The Internet is gaining widespread use in both homes and offices. Most Internet applications use high-speed transfer rates in the downstream direction from central office (CO) to remote unit (RU), and lower bit rates in the upstream direction from RU to CO. The transmission is full duplex; the transmit and receive happen simultaneously. Once the connection is established, it is desirable to maintain the connection even during idle periods.

For Internet applications, downstream data transmission rates at any given time depend upon current customer data download requests. This usually does not occur continuously (non-interrupt) during the connection. Figure 1 shows the transmit portion of one ADSL modem connected through a channel to the receive portion of another modem. In this system both valid and idle data are treated the same - both forms of data pass through the entire encoding and decoding operations; crc, mux, synch, etc. Because idle data transmission conveys no information, many of the encoding and decoding operations could be eliminated with no decrease in data throughput. However, some form of filler data that does not require modulation/demodulation must be put in its place and a method of controlling system state transitions must be implemented.



**Figure 1**.General data flow during xDSL modem connection

In xDSL systems, many modems are co-located in the telephone company central office where the Internet service provider establishes a connection between the modems to the backbone data network, thus connecting the residential customers to the network. Although many modems may be connected at once, not all are transmitting valid data. Therefore, the methods presented provide a mechanism for reducing the required computations, allowing computing resources to be shared among connections using statistical multiplexing. The greater percentage of time that an xDSL connection is in the idle state, the greater is the computational savings.

## 2. DESCRIPTION

#### 2.1 General

We propose two methods for managing an established ADSL connection that enable complexity reduction through the use of special idle data sequences and idle status signaling. These methods re-route the idle data frame through a new path that avoids full use of the modem's processor because full coding, modulation, demodulation, and decoding are not applied to the idle data sequences. During idle periods, we generate an idle signal that has the same spectral characteristics as a signal conveying valid data - thus we maintain spectral compatibility with ADSL. This is similar to the current ADSL standard where an idle signal is generated, scrambled, and modulated so that it appears to the rest of the system as valid data. However, our methods maintain spectral compatibility without using many of the computations required to send true ADSL idle data.

Both methods use a pseudo-noise (PN) signal that is generated and processed one frame ahead of time; this is possible because the PN sequence is data independent. The PN signal will be transmitted in the place of a DMT frame of data, and hence must be conditioned to convey the required synchronization information. Specifically, it must carry synchronization on the pilot tone (tone number 64 of the downstream DMT multiplex and tone number 16 of the upstream) as per the T1E1.413 standard [1]. This can be achieved by first estimating the component of the PN signal that would be decoded at tone number 64 of a DMT receiver. This component is then removed and a new component is added that contains both the synchronization data and signaling information used to indicate the idle/valid status of current or future frames of data.

# 2.2 Description of method 1: Self-contained valid/idle frame status

During standard ADSL transmission of valid data, both the data and the pilot tone are unaffected. When the entire frame contains idle data, the transmitter avoids modulation computations by using the data output from the special PN generator instead. The phase of the pilot in the PN signal is rotated by 180 degrees to indicate to the receiver that the current frame contains the special PN idle data and need not be demodulated. Because the phase of the pilot tone in a given frame indicates the valid/idle status data of that frame, the signaling information is self-contained in the frame. The data transmitted in a frame is unaffected by the data in past or future frames. Basically, the phase of the pilot tone in the current frame relays only information about the current frame and nothing about the next frame.

#### Two situations can occur:

- *valid data in the current frame*: transmit valid data with the regular pilot tone
- *idle data in the current frame:* transmit a PN sequence with a pilot tone added that has the phase rotated by 180 degrees

Figure 2 shows a state diagram that further explains the state transitions and the pilot phase transmitted by a system implementing this method. The system is in the "valid" state while valid data is being transmitted and in the "idle" state while idle data is being transmitted. While in the valid state, the next state can be either valid or change to idle. If the next state is valid, then we send the valid data in the current frame with the regular ADSL pilot tone. If the next state is idle, then we also send the valid data in the current frame with the regular ADSL pilot tone. While in the idle state, the next state can be either idle or change to valid. If the next state is idle, then we send the idle data in the current frame with the phase of the pilot tone reversed. If the next state is valid, then we also send the idle data in the current frame with the phase of the pilot tone reversed. Basically, the phase of the pilot tone in the current frame relays only information about the current frame and nothing about the next frame. The two states, valid and idle, represent the system state as well as the data type being transmitted in the current frame. The transitions between states are labeled with the type of data and the phase of the pilot tone being transmitted in the current frame. Starting from the valid state, the system can either remain in the valid state or change to the idle state. If the next state is valid or idle, then valid data with the normal pilot tone is transmitted. Once in the idle state, the system can either remain in the idle state or change to the valid state. If the next state is idle or valid, then the PN sequence with the phase-rotated pilot is transmitted. Because the required phase of the pilot tone in the PN sequence transmitted in the current frame is known a priori, the PN sequence is generated ahead of time with the PN frequency component at tone 64 removed and a phase reversed pilot tone put in its place.



Figure 2. State diagram of the proposed method 1

# 2.3 Description of method 2: Pilot tone in current frame indicates change in status of next frame

This method uses PN sequences for spectral compatibility as in Method 1 as well as a signaling scheme to indicate idle/valid status to the receiver. However, in this method the transmitter determines the type of data in the next frame and sends this information to the remote receiver during the present frame. Therefore, a buffering at the transmitter is required to collect the future data and analyze it before the current frame is transmitted. The receiver knows a priori if the next frame is to be decoded or not and can act accordingly.

Figure 3 shows a state diagram that further explains the transitions of the system and the pilot phase

transmitted during state transitions. The two states, valid and idle, represent the system state as well as the data type being transmitted in the current frame. The transitions between states are labeled with the type of data and the phase of the pilot tone being transmitted in the current frame. Starting from the valid state, the system can either remain in the valid state or change to the idle state. If the next state is valid, then valid data with the normal pilot tone is transmitted. If the next state is idle, then valid data with a phase-rotated pilot tone is transmitted to indicate to the remote receiver that the next frame will contain idle data. Once in the idle state, the system can either remain in the idle state or change to the valid state. If the next state is idle, then the PN sequence with the phase-rotated pilot is transmitted. If the next state is valid, then the PN sequence with the normal pilot phase is transmitted to indicate to the remote receiver that the next frame will contain valid data.

Regardless of the data carried in the current frame, the phase of the pilot tone always relays information about the next frame, i.e. the phase is independent of the data in the current frame. Because the required phase of the pilot tone in the PN sequence transmitted in the current frame is unknown a priori, the PN sequence is generated ahead of time with the frequency component at tone 64 removed. After analysis of the next frame to determine the pilot phase required, the pilot tone with the appropriate phase is added to the PN sequence on-the-fly. The preferred embodiment for generating the special PN sequence with the correct pilot tone information is identical to that discussed previously for Method 1, but the timing of the operations is adjusted to produce the PN sequence just before transmission.

This technique reduces the number of computations during idle times in both the transmitter and receiver by avoiding full modulation and demodulation. Both methods use modulation of the pilot tone for the transmitter to indicate to the receiver the status of current/next frames of data. This method modulates the phase of the pilot tone to indicate to the remote receiver the status of the data in the current frame.



Figure 3. State diagram of the proposed method 2

# 3. COMPARISON OF THE TWO METHODS

Both methods 1 and 2 rely on the transmission of PN signals that are produced using low-complexity techniques to provide spectral compatibility with the ADSL standard.

Both methods reduce the number of computations during idle times in both the transmitter and receiver by avoiding full modulation and demodulation. Both methods use modulation of the pilot tone for the transmitter to indicate to the receiver the status of current/next frames of data. However, the meaning of the pilot modulation varies for the two methods. Method 1 modulates the phase of the pilot tone to indicate to the remote receiver the status of the data in the current frame, while Method 2 modulates the phase of the pilot tone to indicate the status of the data in the next frame.

The convenience of Method 1 is that no buffering at the transmit side is required. However, pilot phase detection is required at the receiver for every frame. The phase detection in Method 2 is avoided during decoding of valid data (simply check the sign of tone 64) and does not add any computational burden. However, Method 2 requires the extra buffering of the next frame. The use of one method versus the other is application dependent.

**Numerical Example:** Here is an example of the computational saving. These numbers are approximate. About 80% of the total processing power of an DSL modem can be used by the valid data path, whereas an idle

data path using the proposed methods can use only about 10% processing power. To show the benefit of multiplexing, let's assume we have a resource serving 4 active links at full rate (always at valid state). Four links is the lower bound on how many active links we can have with this resource. However, using the proposed method and the same resources, we can have up to 13 active links at idle state. This number 13 constitute the upper limit. On the average, if a link is about 50% valid and 50 % idle, using the same resource, we can have 6 active links. Thus starting with a 4 full links, with the proposed method, we can multiplex 6 active links, which correspond to 2/6 (or 33%) cost reduction.

### 4. SUMMARY

Two methods for reducing computational requirements during idle transmission in digital subscriber line (DSL) modems are presented. Both methods reduce processing power during idle transmission. Modulation computations in the transmitter are replaced with low-complexity pseudo-noise (PN) generation techniques that produce an idle signal that is spectrally compatible with xDSL systems. The PN signal is modified to convey the pilot tone information. The phase of the pilot tone is modulated (rotated by 180 degrees) in the transmitter to indicate idle/valid status of the current/next frame to the remote receiver. After detection of idle status at the receiver, most of the demodulation computations are avoided.

These methods are important because during idle times in an xDSL communication link they alleviate the heavy computational burden associated with transmission of valid data. The greater percentage of time that an xDSL connection is in the idle state, the greater the computational savings. In xDSL systems, many modems are co-located in the telephone company central office where the Internet service provider establishes a connection between the modems to the backbone data network, thus connecting the residential customers to the network. Although many modems may be connected at once, not all are transmitting valid data. Therefore, the method presented provides a mechanism for reducing the required computations, allowing computing resources to be shared among connections using statistical multiplexing.

### 5. REFERENCES

 T1E1.413 standard, "Network and Customer Installation Interfaces- Asymmetric Digital Subscriber Line (ADSL) Metallic Interface," American National Standards Institute (ANSI) T1.413, 1995.