Impulse Noise Protection Initiatives in VDSL2 Systems

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Abstract- **In recent years, VDSL2 standard has been gaining popularity as a high speed network access technology to deliver triple play services of video, voice and data. These services require strict quality-of-experience (QoE) and quality-of-services (QoS) on DSL systems operating in an impulse noise environment. The DSL systems, in-turn, are affected severely in the presence of impulse noise in the telephone line. Therefore to improve upon the requirements of IPTV under the impulse noise conditions the standard body has been evaluating various proposals to mitigate and reduce the error rates. This paper lists and qualitatively compares various initiatives that have been suggested in the VDSL2 standard body to improve the protection of VDSL2 services against impulse noise.**

I. INTRODUCTION

Digital Subscriber Line (DSL) technology provides transport of high bit-rate digital information over twisted wire pair infrastructure that is meant for connecting customers to the telephone company network with the goal of providing economic and reliable services. VDSL2 offer transmission of asymmetric and symmetric data rates up to 200Mbits/s on twisted pair at maximum bandwidth of 30 MHz. To achieve such high data rates, sophisticated digital transmission/ reception techniques are used, which compensate for many line and environment impairments such as signal attenuation (using equalization and bit loading), radio frequency noise and impulse noise (using Reed Solomon block codes combined with Interleaving).

This paper is focused towards analyzing the impact of impulse noise in DSL systems and the techniques to provide Impulse Noise Protection (INP). The following three sections are organized as follows.

Section II provides a brief description of characteristic and types of Impulse Noises. These are based on the statistics collected by [2] in the real deployment scenarios. The characteristic of the impulse noise needs to be kept in mind while considering the different proposals of protection. Section III includes information about the requirement of IPTV deployment. This also establishes the impact of Impulse Noise on QoE/QoS. Section IV focuses on the INP schemes proposed for ADSL/VDSL2 systems. A heuristic measure is used to establish the trade-offs between the different protection schemes based on protection provided and implementation complexity. Section V Summarizes key points in the paper and possible areas for further work.

II. IMPULSE NOISE

Impulse noise is burst of energy spikes with random amplitudes, spectra and inter-arrival time. Impulse Noise can be introduced in the loop either by man-made and natural electromagnetic events, e.g. communication equipment, electrical appliances, lighting discharges etc. Due to its non-stationary nature impulse noise does not lend itself easily to a statistical description. The Bernoulli-Weibull impulse noise model [1] is considered suitable for performance analysis of DSL systems. Impulse noise is characterized based on amplitude, spectrum, burst duration, Inter-arrival time (IAT) [2], [3]. The measurements done to collect statistics of Impulse Noise so far, leads to the classification under three different categories based on the amplitude and pulse duration [2], [3]. Table 1 show the behavior description of REIN, PEIN and SHINE [3].

III. IP-TV REQUIREMENTS

IPTV is an upcoming service for broadcast of multimedia, and is considered as one of the important applications using the DSL physical link. IPTV based video is intolerant to packet loss [14] because it is highly compressed using encoding mechanisms such as MPEG-2 and MPEG-4, and can't recover from packet loss at the network layer. Therefore, losing even a single packet of IP-video can produce a visible degradation in video quality. The technical report on triple play QoE requirements [4] specifies parameters to measure the performance of the service.

Table 1 Impulse Noise Types

Impulse Noise	Burst Length	Repetitive	Desired Modem Behavior
REIN (Repetitive Electrical IN)	<1ms	Yes	No bit error
PEIN (Prolonged Electrical IN)	1-10ms	No	No bit error
SHINE (Single Isolated IN)	>10ms	No	No sync loss

QoE is a measure of end-to-end performance of a system based on user's perception. The user experience of the video affected by the IP packet loss, and as per the Triple Play requirements [4], the viewer perception of quality is affected more by the frequency of IP packet loss than by the duration of such loss. QoS on the other hand, is measure of network performance using priority/congestion and is based on packet loss, delay or jitter.

The QoE requirements in [4] limit the mean time between errored minutes (MTBEM). The errors are measured at the IP layer so that at least one error corresponds to at least one IP packet loss in the video stream. It has been shown that the QoE requirements of Standard-definition IPTV could not be met with the Fast Path for longer loop lengths but could be met with the interleaved path of 16 msec. This was possible as the network data rate requirement was low, and the MTBEM was the only parameter to be improved. On the other hand increasing Interleaving delay may not be a viable solution for services requiring higher data rate or lower latency. Further, the results compared in [4] were without the impulse noise. For service providing IPTV services the QoE norms define less than one visible degradation/two hour program and QoS measure allows a packet loss rate of approximately one packet in million seconds [14].

In the event of Impulse noise, the requirements posed in [4], [14] can't be met without an additional impulse noise protection scheme (apart from Interleaver delay). In the next sections various schemes to provide such an error protection are discussed and the trade-off is presented.

IV. PROTECTION SCHEMES

INP parameter in VDSL2 is a measure of minimum amount of protection, in terms of the discrete multi-tine (DMT) symbols that can be recovered if impulse noise occurs in a burst. In order to protect the DSL transmission from the errors introduced by impulse noise various techniques have been proposed in [11], [12].

RS Decoder combined with interleaver is a popular scheme currently used for INP. The scheme is used to ingress impulse noise with different code words sizes and variable interleave depth. This scheme has a limitation that for higher INP requirement one needs higher memory and increase in delay. To meet the higher INP requirement new schemes has been proposed that can be broadly classified into the following techniques:

1. RS-Erasure Decoding
2. Retransmission
3. Frame Blanking/ Repetition

Table 2: RS Encoder parameters

Parameters	Values
Code word length :N	0-255
Redundancy byte: R	0,2,4,6,8,10,16
Interleaver depth : D	1,2,4,8,16,32,64
Correction capability	R/2 (without Erasure)/R (with Erasure)
Memory requirement	ND/2-bytes

In the rest of the paper, the focus shall be on these schemes. Each of these schemes has their advantages operating in specific conditions, and requires specific implementation and protocol specification.

i. RS-Erasure Decoding

The Reed-Solomon (N, N-R) is a linear block code which is capable of correcting up to R/2 errors (R is no. of redundancy bytes) within a codeword. An Interleaver and de-Interleaver combination is used to spread the burst errors across several codewords incurred by the Impulse noise. One of the techniques used to provide protection is to increase the coding gain in the system by increasing the redundancy bits and interleaving depth to protect under severe Impulse noise conditions. This provides additional protection at the expense of data rate and delay [15].The typical parameters for RS-Encoder are given in Table 2.

Conversely, if the information of the location of the error bytes is known beforehand and can be provided to the RS decoder, then up to R errors can be corrected, by the RS-Erasure technique [5], which theoretically doubles Impulse noise protection. According to [12] if the maximum delay is provided as 8 ms, then for INP = 2 the net data rate can be achieved is 67.98 Mbps with RS-Interleaver combination, and for INP = 4 the net data rate reduces to 36.86 Mbps for same maximum delay, where as with RS-Erasure method INP = 4 can be achieved with data rate as 67.98 Mbps.

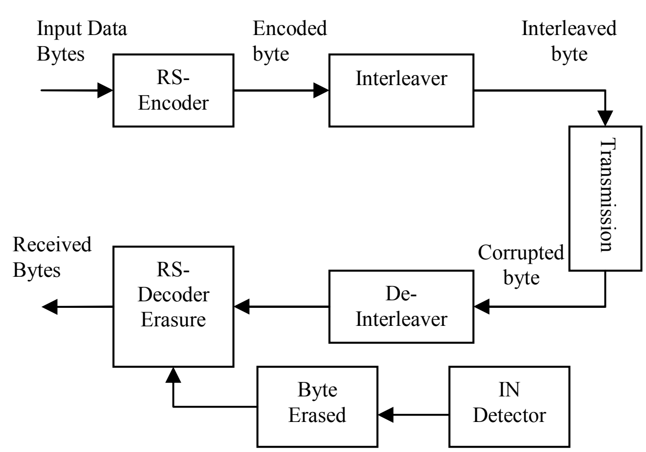

Figure 1: RS-Erasure Decoding

The bytes to be erased/flagged can be done using Demapper data or the Inner code. The RS-Erasure technique hence leads to a better Impulse Noise protection with the same Interleaver configuration. Block diagram of RS-decoding using Erasure is shown in figure 1.

ii. Retransmission

Retransmission is a mechanism used for data transmission to provide reliable communication between transmitter and receiver. It can be use in DSL systems to ensure the correct reception of data affected by impulse Noise. The general principal of retransmission schemes proposed in submissions [6], [7] is depicted in figure2.

In retransmission model Data Transmission Unit (DTU), is the smallest amount of data to be re-transmitted. The transmitted data are stored in a retransmission buffer at the transmitter side. At the receiver frame check sequence (FCS) of the DTU is checked for error. A retransmission request is send if error is found. Even if corrupted, the data unit is pushed in the receive buffer. If the retransmitted data unit arrives while the corrupted one is still present in the receive buffer, the corrupted one is replaced. If the retransmitted data unit doesn't arrive on time, the corrupted data will be further processed by the receiver data path.

Retransmission schemes for low bit error rate are technically feasible, efficient and provide robustness and outstanding performance to DSL transmission (i.e. a channel with a low latency, a high impulse noise protection and a good efficiency). The important control parameters for the technique are –

1. Delay Max = Delay (Retransmission) + Delay (Rescheduling queue)
2. Round-trip delay (delay due to request from receiver to transmitter)
3. The Minimum Inter-Arrival Time (IAT)

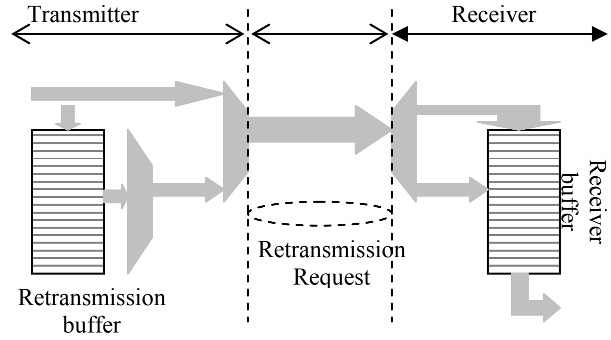

Figure 2: Retransmission Model

Bounds on these control parameter gives full control on retransmission schemes. The retransmission scheme can be implemented at various systems interfaces in DSL. The possible interfaces to introduce retransmission layer are (see figure 3), Application layer, γ interface, α interface and δ interface. This would lead to different DTU sizes and the delay in the scheme.

Retransmission model implementation at application layer or γ interface leads to large roundtrip delay and can't be used for all traffic (e.g. ATM, PTM or STM traffic) [13]. Therefore retransmission model is proposed to implement at α-Interface or γ-Interface [6], [7] for lower roundtrip delay. The typical re-transmission buffer size and minimum delay for VDSL2 implementation at the α-Interface [12] are 25207 bytes and 8 ms.

iii. Frame Blanking/ Repetition

Frame Blanking/ Repetition are transmitter schemes, which can be used to reduce the error due to Repetitive Impulse Noise. The difference between the schemes lie in terms of the data sent during the impulse affected period. In Frame Blanking there is no data transmission during the impulse period [8], [10]; where as in

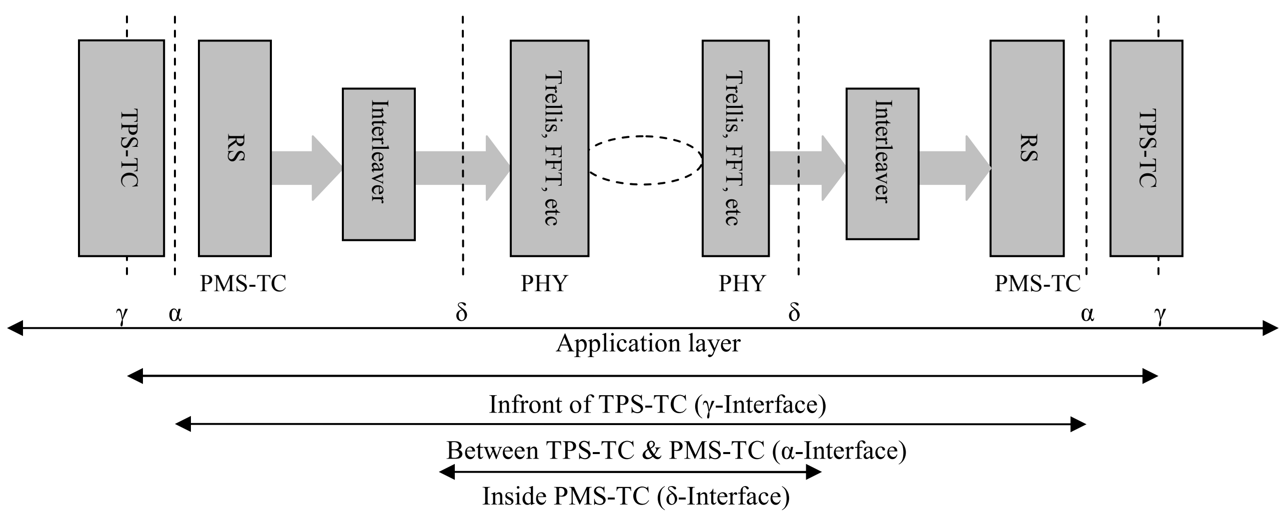

Figure 3: DSL systems Interface

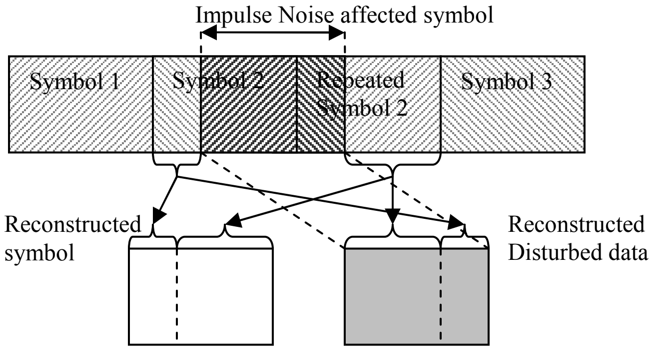

Figure 4: Re-Construction of un-disturbed signal through Frame Repetition [9]

Frame repetition technique [9], the frame is repeated immediately succeeding the impulse affected period. Frame repetition is powerful when used to isolate the impulse pulse overlapping between two symbols. This technique as proposed in [9] can also be used to exactly re-construct the disturbed symbol (see Figure 4 for more details).

Frame blanking/repetition are only useful in the case of REIN. The scheme is not applicable for SHINE and PEIN as the information on the affected symbol may not be known beforehand [10].

iv. Tradeoffs

There are several design considerations which needs to be considered while evaluating the suitability of the scheme, under impulse noise. Some of the considerations are;

- Impulse Noise types
- Latency
- Buffer size
- Implementation complexity
- Inter-operability with legacy systems
- Application

Table 3 Comparison of INP schemes

Impulse Noise Parameter	RS-Erasure	Frame Blanking	Re-transmission
Applicable to Impulse Noises	REIN/ PEIN/ SHINE	REIN	REIN/ PEIN/ SHINE
Latency	Low	Low	High
Buffer size	Low	Low	High
Implementation complexity	High	Low	High
Inter-operability with legacy systems	Interoperable	Can be made interoperable	Not Interoperable
Applicability for voice	Yes	Yes	No

Based on the Table 3, for the low/ moderate INP requirements, it may be better to go for low complexity and interoperable scheme, which would favor RS-Erasure and Frame blanking.

For very high impulse length on the other hand the Re-transmission model may marginal lead to better rates compared to RS-erasure scheme.

V. SUMMARY

In this paper various techniques to INP for IPTV deployments using DSL were presented. Each of the techniques provides optimum trade-off in specific Impulse Noise scenarios and there is no straight winner under all scenarios. Considering the QoE/QoS requirement of IPTV, the scheme selected should provide best performance under REIN and can be sub-optimum in other impulse noise scenarios. The measurement of MTBEM for the various Impulse Noise protection schemes shall help in determining the best candidate.

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