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***Abstract*—An increasing demand from e.g. real-time multimedia applications (IPTV, OTT) adds strains on especially DSL based access links. In this paper we argue why it is important to study DSL link impairments and their impact on QoS parameters on higher layers. We discuss the need for establishing methods for quality of service estimation with cross layer techniques and present some initial results.**

I. Introduction

Digital Subscriber Line (DSL) based access networks are widely spread and used. The number of DSL subscribers worldwide is approximately twice that of optical fibre (FTTx) and cable subscribers [14]. The DSL technology is easy to deploy - the infrastructure is already at hands - but it suffers from some limitations. These limitations have become evident as Internet based distribution of real time media, especially TV, gains popularity. Even though a limited number of DSL lines are experience problems, their contribution to the operator's operational expenditure (OPEX) is so high that the operator's revenue is affected. Thus, it is important to deploy technology that can detect and correct a problem before a subscriber is triggered to call the support. This calls for better understanding and interpretation of measured Quality of Service (QoS) parameters on different layers in the OSI reference model including perceived Quality of Experience (QoE) on the application layer.

Internet based real-time video streaming comes in two flavours: IPTV and Over-the-top (OTT). IPTV systems are in full control by an operator, from video head-end to the user, since the operator is responsible for both the content and the network. OTT uses the public Internet and the content distributers are not controlled by the access network operator. OTT is therefore delivered as unicast and cannot be separated from other best-effort services like web browsing and file downloading. A suggested solution is a media aware, self-adaptive network, a topic studied in the recently finished Celtic project *R2D2* [2]. The full delivery chain, from content server to end user, has to be monitored on all levels by a network resource manager that can automatically take corrective measures in all nodes involved in the delivery.

Even though the number of DSL subscribers worldwide is still increasing, other access technologies are gaining momentum. In Q4 2011 the number of new DSL subscribers were fewer than the number of new subscribers of optical fibre based access links (FTTx) [11]. FTTx can deliver high capacity over longer distances, while DSL technology suffers more from the fact that the higher the capacity required the shorter the physical length of the link have to be. The Celtic project *4GBB* shows that it is possible to increase the link capacity for short distances [1]. 4GBB is a driver for the new ITU-T standard G.fast, which promises capacity in the order of Gbit over distances of 20 to 200 meters.

The deployment of high capacity cellular technologies like Long Term Evolution (LTE) might negatively influence the interest of using DSL technology in access networks. On the other hand, the evolution of cellular networks with respect to more access points or base stations in a denser configuration calls for new backhaul solutions, and in this light DSL solutions are still of great interest.

When investigating the current research, we find a concentration around relationship between QoS on the network layer and QoE on the application layer. Our mission is to take in the full picture, from QoS on the physical and link layers to QoE on the application layer and thus including all layers. Our first approach is DSL, but other access networks techniques, e.g. FTTx and wireless based access networks are also of great interest.

In this paper we present a survey of related work. We also present a study where we describe a disturbance source mimicking a radio station and analyse some effects on IP packet delivery over the disturbed DSL link.

II. Related work

Understanding the relationship between the perceived QoE and the QoS parameters on underlying layers is the basis for the development of new tools and managing systems in this area. Our first approach is to study DSL link behaviour and impact on IPTV and OTT services.

A. Quality of Experience

Users are accustomed to the service and quality level of broadcast television. Therefore, the requirements on real-time video over IP are high. For IPTV, the mean time between visible errors must not be less than four hours [4] [7]. There must be no more than one error second (ES) in the bit stream per hour for standard definition TV and one ES per four hours for high definition TV [12].

To ensure that TV applications, either IPTV or OTT video, meet the end users' QoE expectations, it is necessary to develop tools and methods to monitor and assess the QoE of the video bit stream in real-time. Thus, we have to develop ways to predict perceived quality using just physical QoS characteristics [13].

Due to the efficient compression techniques used in IPTV, packet loss has severe effects. In a study, it was shown that already at a non-recovered packet loss of 0.1% the viewers lost interest and the viewing time decreased with 50% [10]. Note that errors are not only found on the physical layer (bit errors) but are also introduced in network nodes on the network layer; packet discarding is a feature (e.g. Random Early Discard, RED).

The reference for video quality is subjective experiments, which represents the most accurate model for obtaining video quality ratings [15]. In a subjective experiment, a group of viewers are asked to watch a set of video clips and rate the image quality. Disturbances are introduced in a controlled way. The average rating of all viewers for a specific scenario (video plus disturbances) is also called the Mean Opinion Score (MOS). The cross layer interaction between jitter and packet loss and the perceived QoE by the user measured as MOS has been studied in the R2D2 project.

B. DSL Access Link Performance

Over-provisioning has always been a good way to reduce packet loss, delay and jitter in a network. However, IPTV over DSL links does not permit over-provisioning. One bit error might causes the loss of a full L3 packet. DSL bit-error rates of 10^{-7} translate to packet loss rates in the order of 10^{-3}, which approximately produce a visible error every few minutes. [3]

There exist a number of standardised mitigation techniques like retransmission, forward error correction and interleaving on the physical layer of DSL. Naturally, these techniques cannot prevent all errors on the DSL link, and certainly not errors introduced elsewhere in the full path from the content server to the user.

In [9], a refined method for solving the shortages in DSL that introduces packet loss is presented. The method relies on unicast retransmission of lost packets. As a support for a Retransmission Server, Peer-assisted Repair is introduced. A lost packet can be retained from a neighbour Set Top Box (STB) as well as from a Retransmission server. Forward Error Correction (FEC) packets are also used. This calls for updates of the STBs, but also adds demands on the DSL uplink. This requirement is modest according to the authors.

The necessity for DSL error control is discussed in [5]. MPEG-2 TS, the most common transport technique, is designed for low packet loss and jitter, which is not the case in an IP network. Interleaving (in DSL) cannot be made too deep because of increased delay and buffer space. FEC on the application layer (AL-FEC) cannot be utilized too much without hitting delay thresholds; and the protection period is correlated to the well-functioning of channels switching and rewind or fast-forward operations. As a conclusion, a hybrid of AL-FEC and retransmission is suggested to overcome the techniques respective drawbacks, but such techniques are not thoroughly investigated. Physical-layer impairments and error-mitigation techniques for DSL environments are investigated. The objective is to evaluate Forward Error Correction (FEC) as an error-control for IPTV over DSL. The focus is on impulse noise which is a non-stationary stochastic type of noise that is induced due to electromagnetic interference from domestic sources and external events. The paper also discusses admission control, and challenges like Change Time, Network Management and Video Quality Monitoring.

In [6] Begen et. al. discusses the use of Real-time Transport Protocol (RTP) and Real-Time Transport Control Protocol (RTCP) for IPTV distribution. By monitoring RTCP feedback the operator can get a good view of the delivery path's current status.

III. Disturbances and Their Impact in a DSL Environment

Disturbances and noise in a DSL environment can have many sources. Impulse noise from the power line is one example. More or less continuous radio signals can have a negative influence on a DSL link. Poor wiring of the PSTN network is also known to affect a DSL link negative. Depending on the power and the duration of the disturbance the result can be a decrease in capacity, a short interruption of the packet flow or in worst case a total retraining sequence, which causes service loss for tenths of seconds.

The frequency spectrum of interest is for ADSL and ADSL2 systems is 0-2.2 MHz and for VDSL2 0-30 MHz. Switched power supplies, which is a known impairment factor, have a switch frequency of typically 100 kHz, and if faulty generates overtone rich noise. AM broadcast stations are typically found in the spectrum 1-1.5 MHz. Both these sources of disturbance coincide with the DSL frequency spectrum.

Error conditions are indicated by the number of bit swapping occasions, Error Seconds (ES) counted and the number of Cyclic Redundancy Check (CRC) errors during a time period. Of course there are more error indicators, but these are sufficient for the current discussion. While both ES and CRC errors contribute to packet loss a case of bit swappping is normally only an noise indicator. An ES is a time period of up to one second during which an error - CRC error, Loss of Signal or Severely Errored Frame - in the transmission has occurred.

When a DSL line is initialized the Signal to Noise Margin (SNRmarg) is measured for each active tone. The DSLAM continuously controls the SNRmarg for each tone. Bit swapping is used when a tone's SNRmarg is decreased; the constellation for that tone has then to be changed and the number of bits allocated to that tone has to be decreased. If possible, bits are swapped to other tones where the SNRmarg allows more bits. The opposite does not happen when the SNR for one tone is increased; if bits are swapped back to a tone at all it is due to SNRmarg for other tones have been reduced. It can therefore take a long time before the constellation for one tone is restored. Thus, a short time disturbance might influence the link's capacity for a long time.

IV. Experiments

A lab facility for access networks has been implemented. Currently, the testbed consists of a Digital Subscriber Line Access Multiplexer (DSLAM), multiple pair landline cables and Customer Premises Equipment (CPE, 'modems'), an emulated core network and home networks. In the testbed, shown in Figure 1, we have a controlled, practically disturbance free, environment. We can introduce controlled physical disturbances in the DSL link, and analyse how services on any level in

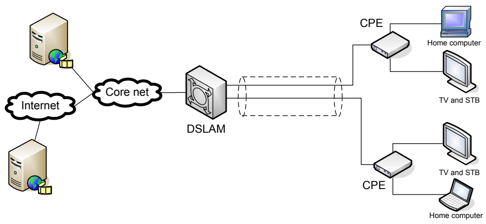

Figure 1. Testbed layout

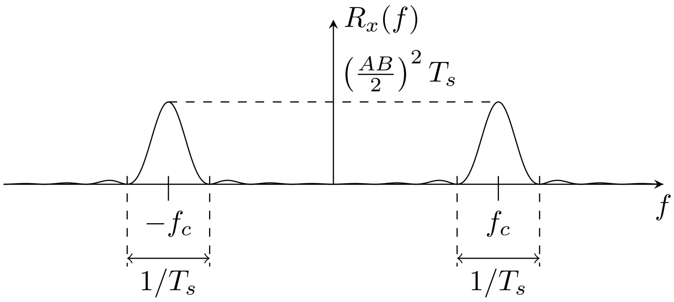

Figure 2. Power spectral density of RF model.

the OSI reference model are affected. Also, different patterns (fingerprints) on different OSI layers can be studied and be linked to special types of disturbances.

One of the disturbance sources we have analyzed is a simulated broadcast radio signal. The disturbance used was a Pulse Amplitude Modulated (PAM) sinus wave. This type of signal has similar power spectrum as that of a broadband radio station. In

$$x(t) = \sum_{k=0}^{\infty} A_k \cdot g(t - kT_s) \cdot Bcos(2\pi f_c t) \qquad (1)$$

$A_k \cdot g(t - kT_s)$ constitutes a bipolar bit stream with the amplitude shifting between -A and +A randomly. f_c is the centre frequency or the carrier frequency, as can be seen in Figure 2 where the power spectrum density of $x(t)$ is shown. The width of the centre lobe is determined by the bit rate of the square wave. The signal power at f_c is a function of A^2, B^2 and the bit time T_s. Thus, we can control where in the DSL spectrum we want to place the disturbance (f_c), how wide the centre lobe should be (the bit rate of the bit stream) and the power of the centre lobe (the amplitude of the bit stream and/or the carrier signal). Figure 3 and 4 show the resulting Quiet Line Noise (QLN) and bit loading pattern versus ADSL tones of a disturbing signal with f_c set to 1MHz and the average bitrate set to 10kbps.

To get a first understanding of the impact of this type of disturbance on a video stream over the DSL link, a UDP packet sender and receiver was connected to the DSLAM and the CPE respectively. For this experiment the RUDE/CRUDE application [8] was chosen. A fixed rate stream of fixed sized packet was used. Packets of 1400 bytes were transmitted each second. The resulting bitrate was approximately 2.5 Mbps. The measurements were performed on the downlink only. Since the clocks in the sender and the receiver were not synchronized only packet loss and jitter was studied; true delay measurement

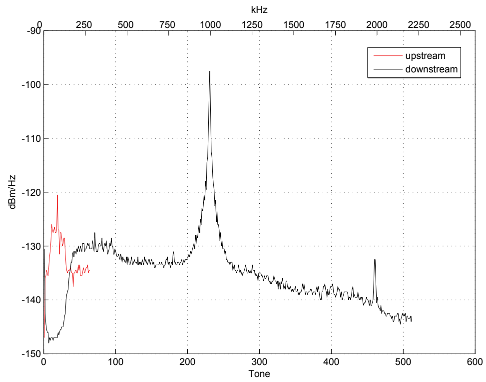

Figure 3. Quiet Line Noise per tone with a disturbing signal at $f_c = 1MHz$, corresponding to tone 233, and the average bitrate $= 10kbps$.

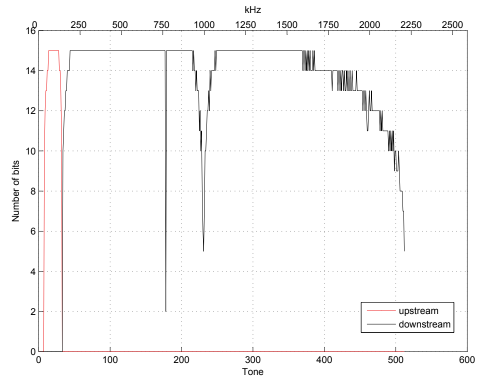

Figure 4. Bitloading per tone with a disturbing signal at $f_c = 1MHz$, corresponding to tone 233, and the average bitrate $= 10kbps$.

could not be performed. Note that the RUDE/CRUDE applications runs in user space in the computer's operating system and thus are affected by kernel activities having higher priority than the measurement application.

During a one hour test run, simulated radio station signals was applied to the DSL link carrying the emulated video stream. The outline of test run is presented in Table I and the resulting packet loss and jitter, or rather inter-packet gap, is shown in Figures 5 and 6. As can be seen, the emulated video stream is affected only by onset of the disturbance; this is in accordance with the discussion above. Also, the impact is increased with higher carrier or centre frequency. With centre frequency at 0.5 MHz, the number of packets lost is in the order of 50, while the packet loss at centre frequency 1 MHz is approximately 300 and at 1.5 MHz it has increased to approximately 800. Note that each packet in a coded video stream carries information for several consecutive

Test section	*Time*	*Disturbance*
1:	0-10min	No disturbance
2:	10-20min	Disturbance at $f_c = 0.5MHz$
3:	20-30min	No disturbance
4:	30-40min	Disturbance at $f_c = 1.0MHz$
5:	40-50min	Disturbance at $f_c = 1.5MHz$
6:	50-60min	Disturbance at varying f_c

Table I
TEST RUN SCHEME

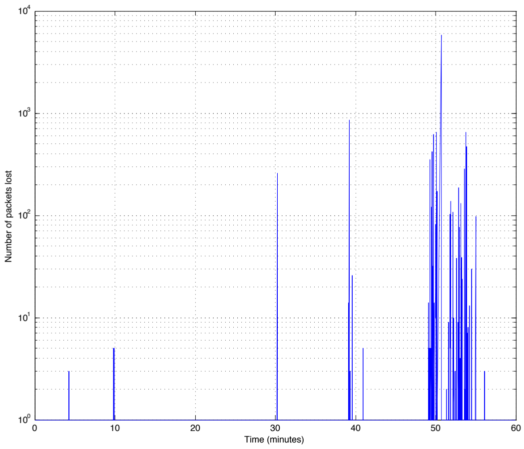

Figure 5. Number of packets lost as a function of time during the experiment.

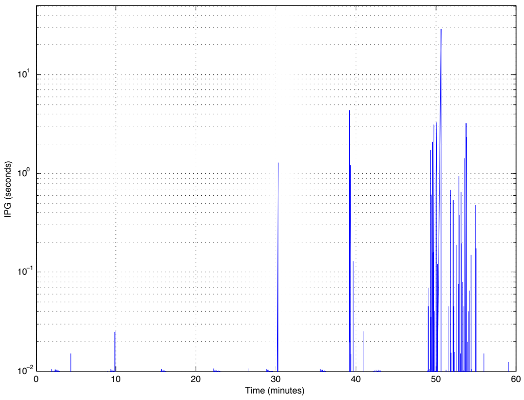

Figure 6. Inter Packet Gap (logarithmic scale) as a function of time during the experiment.

video pictures. The perceived QoE must be affected even for the disturbance with the lowest frequency. The last phase was only to see how much disturbance was needed to trigger retraining; no useful data is found from the last 10 minutes of the test run.

V. Conclusion and Future Work

Support for subscribers of access networks is very costly, and measures have to be taken to find better ways of analysing reported malfunctioning links. This is especially true when it comes to DSL based links. For this, more knowledge of the interaction between the QoS parameters at different layers of the OSI reference model has to be developed. It is important to find out how different types of disturbances that affect the physical layer of a link affects higher layers including the application, and also to find how QoE and or QoS fingerprints on higher layer can be used to find the source of the problem on lower layers.

The influence of different disturbances on bit swapping and error seconds and in turn on datagram jitter and packet loss as well as the impact on the perceived QoE are still to be analysed in depth. It is also of interest to try to establish the opposite relationship, i.e. if fingerprints of jitter and packet loss can indicate a certain type of error or disturbance on the DSL link. The investigations of the impact of faulty power adaptors

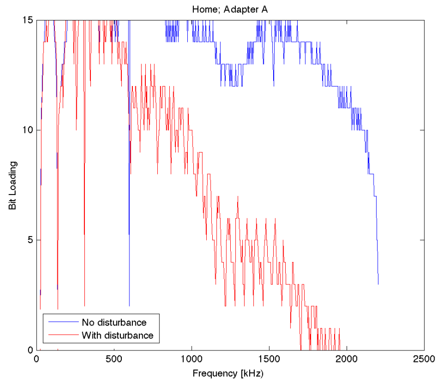

Figure 7. Bitloading pattern with and without interference from a broken power adaptor

(see Figure 7) and other external electromagnetic fields have to be extended. Also other packet generators and receivers that are less vulnerable to influences from the computers operating system have to be found and evaluated. Methods for synchronizing the clocks in the sender and receiver have to be analysed and implemented.

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