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Using Adaptive Quality of Service for OFDM Performance Improvement

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Abstract— **In this paper the multiuser bit allocation problem in discrete multi-tone digital subscriber line networks is investigated under the assumption of the users differing traffic and QoS requirements.**

An adaptive scheme which uses both the varying channel and transport parameters will be introduced for choosing an optimized bit-loading for all users. Depending on the actual traffic consideration, the bit loading will be adapted with respect to the required QoS of the user.

A management entity with knowledge of direct and coupled channel gains allocates the bits within a common binder and control, the received QoS of the users. A cross-layer signalling approach is used for fast and reliable change of transmission parameters.

Index terms— **Adaptive OFDM, Adaptive QoS, AQOS**

I. INTRODUCTION

Recent developments in transmission techniques have led to an impressive growth in the available bandwidth on the link between the end user and the public network. Nevertheless this link is still the bottleneck and therefore the key to the provisioning of broadband applications to the subscribers.

Multi-carrier modulation, like orthogonal frequency division multiplexing (OFDM), may be used to increase the available bandwidth on existing telephony wire technologies such as very high-speed digital subscriber line (VDSL).

The performance of OFDM on DSL lines is strongly influenced by crosstalk which is caused by electromagnetic coupling of the bundled lines within the binder. Due to the near-end crosstalk suppression, far-end crosstalk (FEXT) is most important on VDSL links.

Considering only single users, the data rate is maximized by the "water-filling" approach. Several solutions have been proposed to solve this bit-loading problem [1][2][3][4].

By varying the bit loading of the sub-channels, OFDM may dynamically change the available data rate on the line. Thus the multi-user case must be considered too. In that case a user's bit loading changes the noise experienced by the other users in the same binder. Considering the bit loading and power allocation of all users may be used to improve the DSL performance. Several approaches for adaptation of the bit loading with respect to the other users have been proposed. With iterative water-filling [6], which maximizes the total bit rate of all users under the constraint of maximum per user transmit power, the modems autonomously adapt on the changing channel conditions. However, this approach does not guarantee a minimum data rate for the users and is therefore not appropriate for most practical applications [7]. In [5], the multi-user discrete bit-loading problem is considered with the objective of minimizing the total transmitted power under the constraint of a target sum-rate. This approach tries to achieve a required data rate with a minimum needed power allocation.

All these proposals only deal with the changing channel conditions. In addition it is not known a-priori if the required target sum of the data rates will be achieved. Therefore the quality of service (QoS) of the user may not be guaranteed.

Nevertheless the application parameters, like bandwidth and quality of service requirements, also are time-variant. This variability is not considered in the common bit loading approaches but has great impact on the achieved QoS for the user.

In this paper we present a novel approach which combines both the adaptability of the QoS and channel parameters on VDSL links. QoS parameters, such as throughput and delay, and channel parameters like bit loading will be considered together and adapted to each other.

The remainder of the paper is organized as follows: Section II explains the challenges of the parameter variability. The adaptive QoS concept is described in Section III. Finally, the article concludes with a summary in Chapter IV.

II. VARIABILITY

A DSL binder consists of several (50 and more) subscriber loops. Due to the electromagnetic coupling, crosstalk signals are generated to the other loops. Fig. 1 illustrates the crosstalk.

While near-end crosstalk (NEXT) is generated by the transmitter located at the same side of the

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receiver, far-end crosstalk (FEXT) is induced by the transmitter at the opposite end of the receiver. In VDSL, NEXT is suppressed by frequency division duplexing and is therefore not dealt with in our investigation.

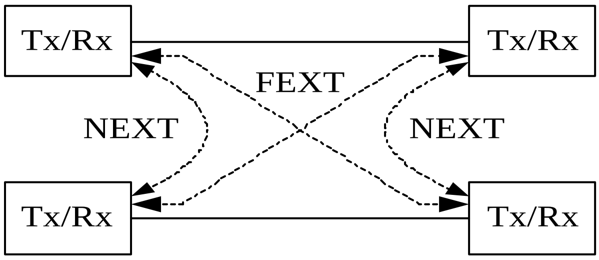

Fig. 1: Crosstalk

The DSL channel with I users is an interference channel with ISI. Due to the spectrum division of OFDM the channel may be modeled as N independent ISI-free sub-channels. The signal-to-interference-plus-mouse ratio (SINR) of user i in sub-channel n is then expressed as

$$(1)\quad SINR_i = \frac{P_i(n) H_{i,i}^2(n)}{N_i(n) + \sum_{j=1, j\neq i}^{I} H_{j,i}^2(n) P_j(n)}$$

where $P_i(n)$ is the signal power, $N_i(n)$ is the background noise power of user i in sub-channel n and $H_{i,i}(n)$ $H_{j,i}(n)$ are the direct and crosstalk channel gain.

The received data rate may be expressed as

$$(2)\quad Rate = \log_2 \left(1 + \frac{SINR}{\Gamma}\right)$$

where Γ is the SNR gap [13].

Thus the data rates of the users depend strongly on the crosstalk, which is caused by the transmission of the other users.

The objective of the multi-user discrete bit loading is to find the bit and power allocation requiring the least amount of total power to transmit a target number of bits per traffic class.

$$(3)\quad \text{minimize} \sum_{i=1}^{I} \sum_{n=1}^{N} P_i(n)$$

$$\text{subject to} \sum_{i=1}^{I} \sum_{n=1}^{N} b_i(n) \geq B$$

A bit cap limits the number of allowed bits to each user in each sub-channel.

$$b_i(n) \in Z_0^{\bar{b}}$$

In addition a power mask constraint limits the maximum power in each sub-channel.

$$P_i(n) \leq \overline{P(n)}$$

The multi-user bit-loading approach in [5] is an extension of the optimal single-user greedy approach [1]. It assigns one bit in the sub-channel that requires the least cost, i.e. the least amount of power increase. The cost is expressed as the minimum total incremental power of all users. Nevertheless the approach does not incorporate the individual QoS requirements of the users.

From the end-user's perspective, the received QoS is most interesting. QoS in that context is characterized by transport parameters like

- Throughput
- Delay
- Jitter
- Packet Error Rate

Assuming a low bit error rate of at least 10^{-7}, which leads to negligible transmission errors on the DSL [20], delay, jitter and loss are all due to the queues traffic experiences while transiting the system. Therefore, providing low delay, jitter and loss for the data streams means ensuring that the data see no or only very small queues [15].

For example, the delay could be expressed as

$$(4)\quad Delay = Delay_{prop} + Delay_{proc} + Delay_{queue}$$

Since propagation and processing delays are a fixed property of the topology or system, delay and jitter are minimized when queuing delays are minimized. In this context, jitter is defined as the variation between maximum and minimum delay [14].

Queues arise when traffic arrival rate exceeds departure rate at some node [15]. Thus, ensuring no or only short queues is equivalent to bounding rates so that, the traffic's maximum arrival rate is less than that traffic's minimum departure rate (Fig. 2).

Unfortunately the arrival rates of several traffic types are time varying. This variability is caused by the self similarity of traffic types, such as WWW, Video, SS7 [8][9][10], the traffic patterns of networks like Ethernet and WAN [11][16], and the user's interaction and activity [17]. In other words, there exists no fixed data rate which is appropriate for the

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arrival rate over all time scales.

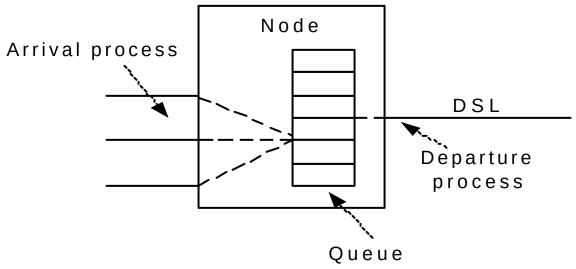

Fig. 2: Arrival and departure process

III. ADAPTIVE QUALITY OF SERVICE

The objective of our adaptive quality of service (AQOS) scheme is the proper adaptation of the DSL departure rate on the arrival rate, to minimize the disturbances and therefore maximize the available data rates on the binder (2). AQOS adjusts the channel parameters (e.g. data rate) to the user's transport parameters (e.g. throughput, delay) and vice versa. AQOS introduces the adaptation of the available data rate on the DSL. The rate will be adapted to the required rate of the users. The rate assignment on the physical layer (PHY) is based on the QoS requirements of the user, i.e. prioritized users will get their rate assignment before the other users. In addition, QoS parameters may be adapted to the current channel and network characteristics, such as load, utilization and available bandwidth. Thus the actual state of the network may be incorporated into the QoS and rate assignment, e.g. during times of low utilization a higher QoS may be provided to the user.

Our AQOS approach combines the parameter handling of both physical channel and QoS. Thus the data rate on the DSL varies over time. The size of the queues within the DSL nodes is controlled by adapting the data rate on the DSL PHY. The queue size is minimized if, even in the short term, the departure rate on the DSL is at least as high as the arrival rate. Thus, the queues will be minimized and the QoS will be improved.

In common QoS approaches, such as Differentiated Services (DiffServ) the QoS requirements of the user will be mapped onto fixed network resources. As mentioned earlier, the resource requirements of current applications vary over time. Due to the large number of streams and the statistical multiplexing within the network, the variability of the streams is smoothed. Thus the mapping of the varying requirements on fixed resources may be done without a high waste of resources.

Within the DSL neither a large number of streams nor statistical multiplexing is available. Thus the common QoS approaches would lead to a high waste of resources.

AQOS avoids this waste by fast adaptation of the QoS requirements on the available resources. The adaptation will be provided by finding a bit loading which satisfies the requirements of the users. If the requirements are lower then the resources, the used resources may also be lowered.

The QoS requirements of the users are characterized by rate settings in different traffic classes. To meet the requirements, the bit load assignment will be done on the basis of traffic classes, i.e. the requests of highest class users will be processed first. Requests of the lowest class will only be provided if all higher class users are satisfied.

Main tasks of AQOS are traffic classification, data rate estimation, and the signaling of the QoS and the channel parameters. Traffic streams will be classified in accordance with the QoS levels. For new streams an estimation of the expected amount of data per class will be calculated. The signaling is used to find and assign the appropriate setting of the transmission and QoS parameters. For the autonomous management of the algorithms, a central entity is used.

A. QoS Sublayer

As mentioned earlier several new functions will be introduces by AQOS. This functionality is split into the data plane and the control plane of the protocol stack (Fig. 3).

The data plane functionalities, such as classification and rate estimation, will be included in an adaptive QoS sub-layer which is part of the data link layer (DLL) of the protocol stack.

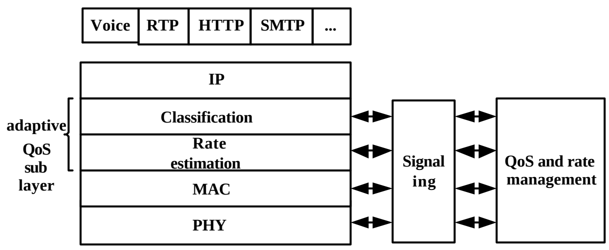

Fig. 3: Protocol stack

The classification may be based on link (e.g. VLAN-ID, priorities), network (e.g. addresses, protocol identifier, DiffServ labels), or transport layer (e.g. port numbers) information. The streams will be assigned to a traffic class. Each class corresponds to a specific service of the network. Several services which meet the requirements of interactive, real-time and non-real-time applications are provided by the network.

Thereafter an estimation of the expected rate within each class is provided. The information may be extracted from signaling messages, profiles, or empiric models of the traffic characteristics. After this estimation, each user's per class target rate $b_i(c)$ is known. The total per class target rate may be expressed as:

$$(5)\quad B_c = \sum_{i=1}^{I} b_i(c)$$

The target sum rate is:

$$(6)\quad B = \sum_{c=1}^{C} B_c$$

B. Signaling

For the proper adaptation, a fast signaling approach is needed. The fast signaling mechanism includes both vertical and horizontal exchange of information (Fig. 4). Signaling and parameter adaptation will be triggered by two different events, i.e. change of the channel conditions and change of the expected traffic volume. The central management entity decides if the changing conditions will lead to a change in the transmission parameters. If that is the case, signaling messages will be delivered. The following signaling sequence will be initiated by the management entity (Fig. 3):

- The local PHY will be asked if the new transmission parameters can be provided.
- The remote MAC will be informed by the local MAC that the transmission parameters will be changed.
- The remote PHY is asked by the remote MAC if the new transmission parameters can be provided.

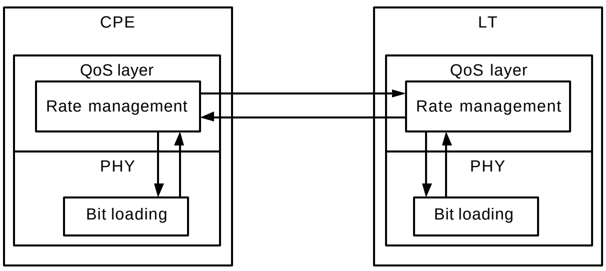

Fig. 4: Signaling scheme

An advanced cross-layer signaling mechanism is used to transmit both channel and QoS parameters in DLL frames. In that context, cross-layer signaling means the combined transmission and usage of information from different protocol layers, i.e. PHY and DLL [12].

Vertical signaling means the exchange of information between different layers within a device, i.e. information from physical layer (e.g. bit loading, power allocation) and QoS sub-layer (per-user and per-class target rates) will be shared used.

Generally, because of the frequency division duplexing the VDSL channels are non-reciprocal [18]. Thus, only closed loop signaling approaches can be used for horizontal signaling. In that case the bit loading decision of the transmitter will be provided by the receiver. This is caused by the fact that the channel may only be estimated by the receiver if the channel is non-reciprocal.

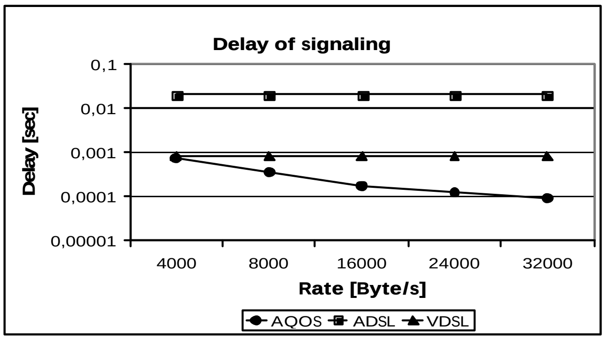

Fig. 5: Signaling delay

Horizontal signaling includes the parameter and state exchange between the modems on the DSL. This information must be exchanged quickly before the adaptation becomes outdated. To achieve this, the signaling will be done in DLL frames and not within a control channel of the physical layer. An advantage of the transmission in DLL frames is the usage of a higher signaling rate. The signaling frames will be transmitted as payload on the DSL. The payload rate commonly is higher than the rate of the operational channel of the PHY. Thus the signaling messages will be delivered faster (Fig. 5). In addition, advanced error protection may also be used for the signaling messages.

Due to the advanced signaling approach in AQOS, the total duration of the parameter negotiation is shorter than 100 msec. In addition the signaling bandwidth is only used if needed. Therefore no bandwidth is wasted during idle times.

C. Management Entity

For the autonomous management of the algorithms a central entity is used [19]. Thus the complete information of the cable binder may be used to negotiate the desired parameters and to control the QoS of all links within the binder.

The heart of the management entity is the QoS enhanced multi-user discrete bit loading algorithm. It could be described as follows:

Initialization:

1. Calculate the cost of transmitting one bit for all users and sub-channels
2. Weight the cost with respect to the QoS requirements
3. Find in each sub-channel the user that requires the minimum cost.

Iteration:

4. Add one bit to the user of the sub-channel with the minimum cost
5. Check if all traffic requirements of the current class are met. If YES choose the next lower class with unsatisfied requirements. If all requirements are met stop the iteration. Otherwise go to step 6.
6. Update and weight the cost for that sub-channel
7. Find the user that requires the minimum cost in that sub-channel. Go to step 4.

The amount of rate improvement depends on the number of reduced disturbers within the sub-channels. Simulations of the approach show that the available data rate on VDSL links may be increased by up to 50%.

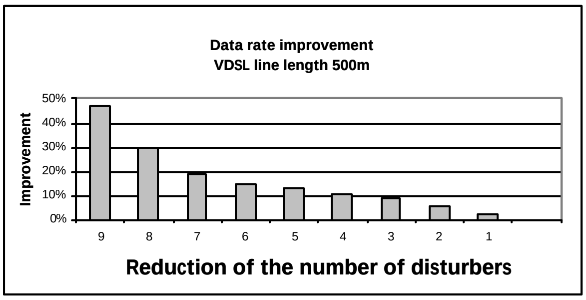

Fig. 6: Rate improvement

IV. CONCLUSIONS

The paper describes a novel approach which combines adaptive control of physical layer parameters and application QoS parameters. Both channel and QoS parameters fit each other. Thus the used data rate is optimized on the real demands and the FEXT is minimized. This leads to significant improvements on the data rate, range and quality of service on OFDM based VDSL links. In addition the service-guarantees to the subscriber may be adapted to the channel utilization.

The main advantage of our approach is the ability to adjust the changing parameters of the channel to the changing applications requirements and vice versa. This leads to an improvement of the available data rate and the range of the transmission scheme. In addition the QoS adaptation may be used to provide better service to the customer and higher network utilization.

V. REFERENCES

[1] D. Hughes-Hatogs, "Ensemble Modem Structure for Imperfect Transmission Media", U.S. Patenst 4 679227, 4731 816, 4 883706, 1987, 1988, 1989

[2] P. S. Chow, J. M. Cioffi, J. A. C. Bingham, "A practical discrete multitone transceiver loading algorithm for data transmission over spectrally shaped channels", IEEE Trans. on Communication, vol. 43, pp. 773-775, Feb./Mar./Apr. 1995

[3] B. S. Krongold, K. Ramchandran, D. L. Jones, "Computationally efficient optimal power allocation algorithms for multiuser communication systems", IEEE Trans. on Communication, vol. 48, pp. 23-27, January 2000

[4] R. V. Sonalkar , R. R. Shively, "An efficient bit-loading algorithm for DMT applications", IEEE Communication Letters, vol. 4, No. 3, pp. 80-82, March 2000

[5] J. Lee, R. V. Sonalkar, J. M. Cioffi, "Multi-User Discrete Bit-Loading for DMT-based DSL Systems", Proc. IEEE Globecom '02, Taipeh, Taiwan, Nov. 2002

[6] W. Yu, G. Ginis, J. M. Ginis, „An adaptive multiuser power control algorithm for VDSL",Proc. IEEE Globecom '01, pp. 394-398, San Antonio, USA, Nov. 2001

[7] S. Pfletschinger, G. Münz, J. Speidel, "Efficient Subcarrier Allocation for Multiple Access in OFDM Systems", Proc. 7th International OFDM-Workshop 2002, Hamburg, pp 21-25, September 2002

[8] M.E. Crovela und A. Bestavros. "Self-Similarity in World Wide Web Traffic: Evidence and Possible Causes." Proc. ACM SIGMETRICS' 96, 1996

[9] D.E.Duffy, A.A. McIntosh, M. Rosenstein, W.Willinger. "Statistical Analysis of CCSN/SS7 Traffic Data from Working Subnetworks." IEEE JSAC, 1994

[10] J. Beran, R. Sherman, M. S. Taqqu und W. Willinger. "Long-Range Dependence in Variable-bit rate Traffic." IEEE Transactions on Communications, Feb./Mar./Apr. 1995

[11] W. Leland, M. Taqqu, W. Willinger und D. Wilson. "On the Self-Similarity Nature of Ethernet traffic (Extendet Version)." IEEE/ACM Transactions on Networking, 1994

[12] Z. J. Haas. "Design Methodologies for Adaptive and Multimedia Networks." IEEE Communications Magazine, Vol. 39, No. 11, pp 106-107, November 2001

[13] J. M. Cioffi, "A Multicarrier Primer", ANSI T1E1.4 Commitee Contribution, November 1991

[14] B. Davie, et.al., "An Expedited Forwarding PHB (Per-Hop Behavior) " RFC 3246, March 2002

[15] V. Jacobson, K. Nichols, K. Poduri, "An Expedited Forwarding PHB", RFC2598, June 1999, Obsoleted by RFC3246

[16] V. Paxson, S. Floyd, "Wide Area Traffic: The Failure of Poisson Modeling" ACM/IEEE Trans. on Networking, 1995

[17] J. Charzinski, "Messung und Modellierung von Internet-Verkehr", ITG Fachtagung, 1999

[18] T. Keller und L. Hanzo. "Adaptive Multicarrier Modulation: A Convenient Framework for Time-Frequency Processing in Wireless Communications." IEEE Proceedings of the IEEE, Vol. 88, No 5, pp 611-640, May 2000

[19] K. B. Song, S. T. Chung, G. Ginis, J. M. Cioffi, "Dynamic Spectrum Management for Next-Generation DSL Systems", IEEE Comm. Mag., Vol. 40, no. 10, pp 101-109, Oct. 2002

[20] T. Langguth, et. al., "Performance Study of Access Control in Power Line Communication", 4th International Symposium on

Power-Line Communications and its Applications, Limerick (IR), April 2000