Modelling of Data Stream Time Characteristics for Use of Inverse Multiplexer

Petr JARES, Jiri VODRAZKA

Department of Telecommunication Engineering, Faculty of Electrical Engineering, Czech Technical University in Prague, Technicka 2, 166 27 Prague 6, Czech Republic

petr.jares@fel.cvut.cz, jiri.vodrazka@fel.cvut.cz

Abstract. *Today, increasing of the transmission rate in a telecommunications network is possible in various ways. One of them is inverse multiplexing. The inverse multiplexer divides a data stream to multiple parallel channels. This principle not only allows to increase the total available transmission rate, but also allows to reduce the error rate and interruption in data stream. The digital subscriber line may be used for the implementation of the inverse multiplex. Accurate knowledge of the transmission parameters of a digital subscriber line and the entire infrastructure of the network provider is necessary for the effective functioning of the terminal device with inverse multiplexing. It is necessary to know not only the parameters related to the transmission rate, but above all the parameters relevant to the time characteristics of data transmission. This paper describes how to obtain the transmission parameters of real digital subscriber lines and their modelling.*

Keywords

Digital subscriber line, inverse multiplexing, packet delay variation, transmission delay.

1. Introduction

The increase of a transmission rate or the error-free data transmission in telecommunication networks can be done with the use of different methods. The inverse multiplexer on transmit side divides a single data stream into multiple parallel data channels and the multiplexer on receive side puts together data from all channels to single data stream [1].

The inverse multiplexing requires installation of the special network element - multiplexer/demultiplexer (the Muldex) - one on the end user side and one on the service provider side. On the transmitting side, the Muldex is responsible for the proper packets distribution in the particular channels with respect to the current transfer conditions and the selected transmission mode (speed increase, higher reliability). Therefore, on the transmitting side the Muldex must have the accurate information on the characteristics of data channels.

On the receiving side the Muldex is responsible for the proper arrangement of received packets, so they are set up into the original sequence (packet on transmitting side are numbered sequentially), and for the next hop. In the transmission mode, which increases fault tolerance, the Muldex must decide which of the received packet is error-free and which has to be discarded. The transmitted data are encapsulated into proprietary communication protocol. The described principle of inverse multiplex is shown on the Fig. 1.

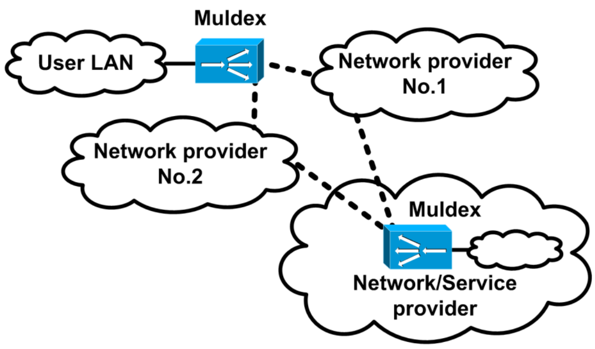

Fig. 1: The principle of inverse multiplexing.

The Muldex must be fully transparent for the TCP/IP protocol family. The reason is, the transmission channel is formed by networks of multiple network providers. The picture shows the parallel paths through two independent network providers presented by a dashed line. Two Muldex devices are placed on the user's end and the service provider side [2].

2. Experiments with Inverse Multiplexer over DSL

Today, realistically achieved transmission rate in the digital subscriber lines ADSL2+ and VDSL2 (in general xDSL) in the downstream direction is in the order of few to tens of Mbps. Reached speeds in the upstream direction are significantly lower. Usually there are hundreds of kbps to few Mbps. The resultant value of the transmission rate is affected by the type of digital line, the actual conditions of the transmission, a network infrastructure of the provider and concentration (aggregate) point.

Development of the digital subscriber lines has not finished yet, and VDSL2 will not be the last one. The new ITU-T G.9701 recommendation allows further use of a metallic line in the last mile of the access network. When using the twisted pairs for data transmission with gigabit rate is expected [3].

2.1. Network Infrastructure of the Digital Subscriber Lines

The network infrastructure is illustrated on Fig. 2. The diagram shows the xDSL line, aggregation network infrastructure including aggregation point and backbone networks of the multiple network providers. The aggregation point combines data streams from end users [4]. At this point, data packets are classified in the priority queues. When these queues are full, next incoming packets are dropped. Therefore, increased the delay packet transmission and packet loss may occur due to the existence of priority queues. Features of the aggregation point may also cause packet delay variation during the transmission [6], [8].

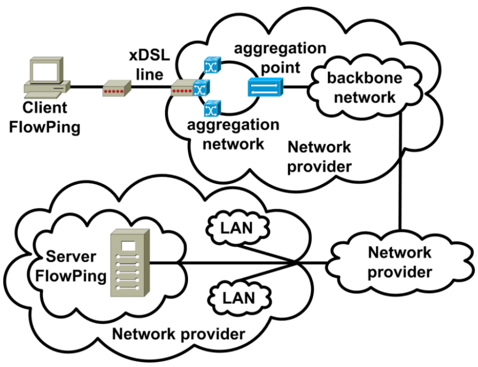

Fig. 2: Typical xDSL network infrastructure.

For testing use, at both ends of the transmission circuit a personal computer must be present. The software application FlowPing has been used for analysis of transmission parameters. The FlowPing server has sufficiently sized bandwidth (Ethernet 1 Gbps), so it will not affect the results of measurements of the digital subscriber line parameters. As already mentioned, for xDSL lines data transmission in the upstream direction is slower than in the downstream direction. Therefore, it is assumed that inverse multiplexer will enforce mainly the weaker direction of data transfer.

2.2. Measuring Data Transmission Time Characteristics of the Digital Subscriber Lines

Currently, a large number of diagnostic tools for the analysis of the data channels transmission parameters or bi-directional data links are available. In most cases, these applications are able to measure only the value of the maximum achievable transmission rate and the transmission Round Trip Time (RTT).

However, these parameters are insufficient for implementing inverse multiplexer. During the transmission, the Muldex must have available not only the value of the current transmission rate, but also information about the current Packet Loss (PL), Packet One Way Delay (OWD) and Packet Delay Variation (PDV).

Custom developed application FlowPing [5] is able to accurately test the parameters of the data channel. On the transmitting side (FlowPing client) application generates precisely defined UDP (User Datagram Protocol) stream and creates log files. On the receiving end (FlowPing server), incoming packets are processed, and activity is logged. The FlowPing client and server are synchronized using the NTP protocol.

Thanks to log files post-processing, it is possible to obtain information about the parameters of the data channel. For example, due to internal clock synchronization of the testing PC running client of FlowPing application and testing server running server of FlowPing application, it is possible to calculate OWD parameter as time difference between receiving time and transmitting time for each packet. PDV parameter is calculated as the difference between OWD mean value and OWD value of a particular packet.

Analysis and theoretical modelling of these and other results are needed to control the Muldex. Knowledge of the behaviour characteristics of the data channel in time can help to prevent abnormal and unwanted states during data transmission.

2.3. Transmission Parameters of the Experimental Digital Subscriber Lines

For the Muldex management requirements the transmission characteristics of two real lines, ADSL2+ from first provider and VDSL2 from the second provider, were measured. Basic parameters of the lines are shown in Tab. 1.

Tab. 1: Basic xDSL lines parameters.

Type of xDSL	Actual net data rate [kbps]	
	Upstream	Downstream
ADSL2+	515	8199
VDSL2	1415	24127

Parameters of the tested data stream are listed in the Tab. 2.

Payload filed size of UDP protocol packet was always 1464 B. Profile of the test data stream gradually loads the data channel with the increasing transmission rate. With the gradual increase of the transmission rate to a maximum value, an influence of the aggregation point and the network infrastructure can occur. The results of previous tests have shown that the data stream of ADSL2+ or VDSL2 is not affected by the value of the transmission rate to 75 % or 90 % of Actual Net Data Rate. The maximum value of 100 % of Actual Net Data Rate cannot be achieved with regard to the existing protocol structure PPPoEoA (ADSL2+) and PPPoE (VDSL2). Actual Net Data Rate is the transmission rate provided to higher communication layers by xDSL physical layer.

Tab. 2: Parameters of the testing data stream.

Time [s]	Test profile ADSL2+	Test profile VDSL2
	Percent of actual net data rate	Percent of actual net data rate
0	75	90
900	85	96.5
1800	85	96.5
2700	87	97.2
3600	87	97.2
4500	89	98
5400	89	98

2.4. Modelling of the Subscriber Line Delay

For each of the lines, a total of 40 tests were performed. The tests were carried out at different times of the day and different days of the week.

For ADSL2+ line it was found that the value of the maximum transmission rate V_{pmax} is equal to 89 % of the Actual Net Data Rate. This fact corresponds to the used PPPoEoA protocol structure, because this protocol structure requires approximately 11 % for the service communication (overhead). Before reaching V_{pmax} rate, OWD value equals 28.4 ± 1.2 ms (level of significance 95 %).

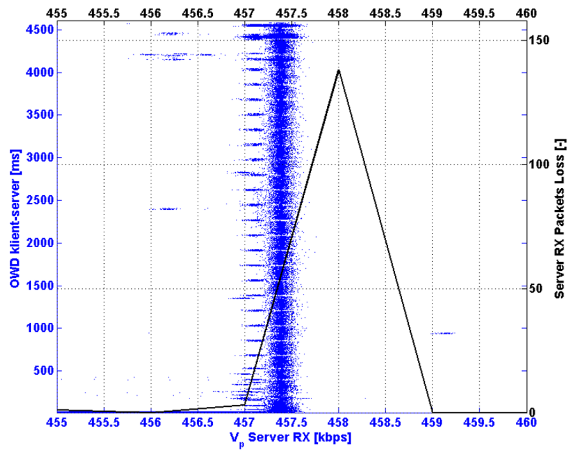

Fig. 3: The measured values of OWD and packet loss.

The graph on Fig. 3 shows the packet OWD (blue points) and packet loss data stream (black curve) dependency to its bit rate on the receiver side. The packet loss is calculated with 1 kbps interval, and it is always carried by a higher value in the interval. The graph evidently shows that up to V_{pmax} value, data transmission was error free. With transmission rate of V_{pmax} stream the OWD value is increased approximately 140 times and then PL starts to increase as well. In general, increase of PL occurs, when buffers of network elements are full, so transmission of other incoming packets is not possible.

Possible increase of PL before reaching V_{pmax} value can have several reasons. In general, in xDSL technology, it is possible that due to influence of external disturbance, during transmission, packets will be lost even if the V_{pmax} value was not reached. It is also possible that aggregation point on purpose denied specific packets of particular data flow to decrease transmission rate by using principles of TCP protocol (Transmission Control Protocol). The data flow tested in FlowPing application uses UDP protocol, where transmission rate is not affected by packet-loss of data channel.

The Goodness-of-Fit test (Kolmogorov-Smirnov) confirmed that it was possible to model the packet delay variation parameters of ADSL2+ lines with the logistic distribution with Probability Distribution Functions (PDF) according to Eq. (1):

$$f(x) = \frac{e^{\frac{x-\mu}{\sigma}}}{\sigma\left(1+e^{\frac{x-\mu}{\sigma}}\right)^2}. \tag{1}$$

Distribution parameters are listed in Tab. 3. These values were obtained using Maximum-Likelihood Estimation (MLE). The following graph shows the PDV histogram and modelled theoretical (red curve) PDF logistic distribution.

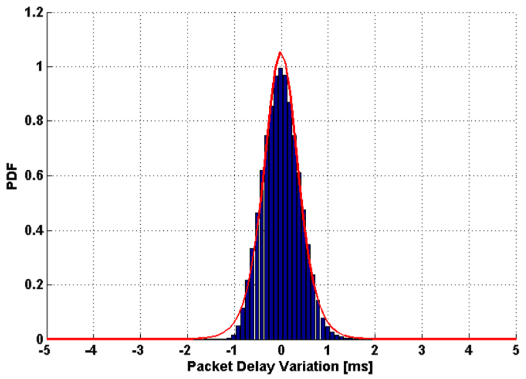

Fig. 4: Comparison of ADSL2+ PDV histogram and PDF logistic distribution.

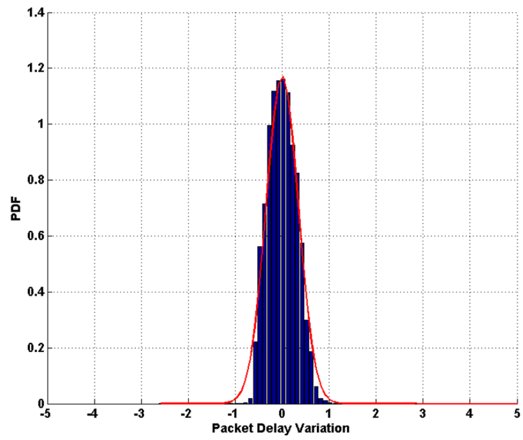

Fig. 5: Comparison of VDSL2 PDV histogram and PDF normal distribution.

Tab. 3: Parameters of the PDF logistic distribution.

Parameter	Value	Confidence interval	
		Low 5 %	High 95 %
Location μ [s]	−0.006	−0.00827	−0.00416
Scale σ [s]	0.2372	0.2372	0.2382

In the same way, the measured parameters from the VDSL2 line from the second provider were analysed. For this line it was found, that the maximum possible value of the transmission rate Vpmax is approximately 98 % of Actual Net Data Rate. PPPoE protocol structure requires overhead of around 2 %. Relation of OWD value to V_{pmax} is approximately 19.4 ± 9 ms (level of significance 95 %).

The Goodness-of-Fit test confirmed that PDV parameters can be statistically modelled by a normal distribution, which has the values listed in Tab. 4.

Tab. 4: Parameters of the PDF normal distribution.

Parameter	Value	Confidence interval	
		Low 5 %	High 95 %
Mean [s]	$-2 \cdot 10^{-5}$	$-1 \cdot 10^{-3}$	$9 \cdot 10^{-4}$
Variance [s^2]	0.340	0.339	0.341

The following graph shows the PDV histogram and compliance with the theoretical Probability Distribution Functions of the normal distribution.

3. Conclusion

From a technical point of view, ADSL2+ and VDSL2 lines are very similar, both use the same modulation principles and the same method of the data protection during data transmission.

With regard to the same concept of the aggregation network infrastructure of network provider (incumbent's network in the Czech Republic), the same function of the aggregation point for both lines can be assumed. Generally, it can be said, that the aggregation point significantly does not affect the parameters of the data stream in the upstream direction. With respect to the existing protocol structure, both lines achieved almost theoretical maximum transmission speed values. In addition, the achieved value did not change during the day or in different days of the week.

Different time characteristics of the data channel which implement both lines are probably influenced with the next network infrastructure provider. The OWD values for ADSL2+ are higher than for VDSL2. The OWD in VDSL2 is less stable with a higher variance. With regard to the limit parameters of nowadays usually used services (e.g. limit value of 20 ms for VoIP or TDM over IP [7]) delay variation for both lines is generally very small. Packet delay variation for these two lines has different statistical dependencies for modelling. Although the PDV has similar nature for both xDSL systems, for ADSL+ it correlates empirically determined histogram of PDV amplitudes with the logistic distribution. During data transmission, VDSL2 technology has less stable time characteristics, for example, with bigger value of PDV variance.

For theoretical modelling, better correspondence between empirical PDV histogram and the distribution function of the normal distribution is visible. As already mentioned, ADSL2+ and VDSL2 use the same principle on the physical layer of OSI model, but implementation on higher communication layers is different. Also, the network infrastructure behind aggregation point has different parameters. All this is obviously visible in distinctive time characteristics of transmitted data flows in both technologies.

To control network element with the function of inverse multiplexing, the results of behaviour of both lines are important. This means value of the maximum achievable transmission rate, a way of OWD increase and the corresponding parameter of packet delay variation during the transmission will be used for set of the packet regulator in the inverse multiplexer [2].

Acknowledgment

This work was supported by the Grant of the Technology Agency of the Czech Republic, No. TA02011015, „Research and development of a new communication system with multi-channel approach and multi-layer co-operation for industrial applications", and was researched in cooperation with CERTICON.

References

[1] CHLUMSKY, P., Z. KOCUR and J. VODRAZKA. Comparison of Different Scenarios for Path Diversity Packet Wireless Networks. *Advances in Electrical and Electronic Engineering*. 2012, vol. 10, no. 4, pp. 199–203. ISSN 1336-1376. DOI: 10.15598/aeee.v10i4.713.

[2] KOCUR, Z., P. MACEJKO, P. CHLUMSKY, J. VODRAZKA and O. VONDROUS. Adaptable System Increasing the Transmission Speed and Reliability in Packet Network by Optimizing Delay. *Advances in Electrical and Electronic Engineering*. 2014, vol. 12, no. 1, pp. 13–19. ISSN 1336-1376. DOI: 10.15598/aeee.v12i1.878.

[3] NEVOSAD, M., P. LAFATA and P. JARES. Modeling of Telecommunication Cables for Gigabit DSL Application. *Advances in Electrical and Electronic Engineering*. 2013, vol. 11, no. 5, pp. 336–341. ISSN 1336-1376. DOI: 10.3403/30169077.

[4] STARR, T., M. SORBARA, J. M. CIOFFI and P. J. SILVERMAN. *DSL Advances*. Upper Saddle River, USA: Prentice Hall, 2002. ISBN 9780130938107.

[5] VONDROUS, O. *New UDP Based Methodology for Throughput and Stress Tests*. Prague, 2013. Available at: `http://www.flowping.comtel.cz`.

[6] VOZNAK, M. and M. HALAS. Delay Variation Model with RTP Flows Behavior in Accordance with M/D/1 Kendall's Notation. *Advances in Electrical and Electronic Engineering*. 2010, vol. 8, no. 5, pp. 124–129. ISSN 1336-1376.

[7] VODRAZKA, J., P. JARES and P. LAFATA. Time Division Multiplex over Packet Oriented Digital Subscriber Line. In: *Proceedings of 15th Mechatronika 2012*. Prague: Czech Technical University in Prague, 2012, pp. 177–181. ISBN 978-80-01-04985-3.

[8] VODRAZKA, J. and P. LAFATA. Transmission Delay Modeling of Packet Communication over Digital Subscriber Line. *Advances in Electrical and Electronic Engineering*. 2013, vol. 11, no. 4, pp. 260–265. ISSN 1336-1376.

About Authors

Petr JARES is an assistant professor at the Department of Telecommunication Engineering, Faculty of Electrical Engineering (FEE), Czech Technical University in Prague (CTU in Prague). He received his doctor (Ph.D.) degree in 2008 at FEE, CTU in Prague, specializing in Telecommunication Engineering. For past few years he has worked on various projects in the transmission systems. His current focus of interest is on data transmission in the metallic and optical access networks.

Jiri VODRAZKA was born in Prague, Czech Republic in 1966. He joined the Department of Telecommunication Engineering, FEE, CTU in Prague in 1996 as a research assistant and received his Ph.D. degree in electrical engineering in 2001. He has been the head of the Transmission Media and Systems scientific group since 2005 and became Associate Professor in 2008. He participates in numerous projects in cooperation with external bodies. Currently he acts also as vice-head of the Department.