Analyzing Influence of the Transmission Medium on Timing Signals Transmitted by Hybrid Optical Transport Technologies

Rastislav Róka and Veronika Dolinayová

***Abstract*— The contribution deals with synchronization aspects in SDH and Synchronous Ethernet timing networks utilizing optical transmission medium. First, it explains a hierarchical configuration of timing network elements, characterizes transmission features of the optical fiber, particularly its main negative influences influencing transmitted information signals. The main part is dedicated to the evaluation program created for analyzing influences of the optical transmission path on timing signals transmitted by SDH and SyncE transport technologies. At last, resultant values from the introduced evaluation program are presented and evaluated.**

***Keywords*— optical transmission medium, SDH and Synchronous Ethernet Technologies, timing networks, transmission parameters.**

I. Introduction

For developing future services and applications [1], [2], solving of synchronizations for digital signals transmitting in telecommunication networks must be globally applicable and beneficial. Therefore, synchronization is one from key aspects at the signal transmission through metallic, optical or other transmission media by various different technologies [3], [4]. From the synchronization viewpoint, digital transmission networks can be divided into two groups – synchronous and asynchronous. In this contribution, we focus on timing signals transmitted by SDH (Synchronous Digital Hierarchy) and SyncE (Synchronous Ethernet) technologies utilizing the optical transmission medium.

For the signal transmission in SDH and Synchronous Ethernet networks, a dominating transmission medium is the optical fiber. It is a fact that various negative environmental effects influence any information or timing signals transmitted through the optical transmission medium. To the most important belong an attenuation occasioning the optical impulse's amplitude decreasing and a dispersion occasioning the optical impulse's time expansion. From a viewpoint of digital transmission technologies, these effects become expressively evident by changing of transmission parameters. Therefore, a maximum transmission rate in the optical medium is finite and a signal is transmitted to the definite transmission distance depending on the optical source, parameters of the optical fiber and the optical receiver at the optical transmission path's end. In this contribution, the aim is focusing on the optical transmission medium and its impact on transmission parameters of timing signals utilized by SDH and Synchronous Ethernet technologies. The created evaluation program can be utilized for evaluation of exploited optical transmission paths transmitting digital signals of future services and applications.

II. SDH and Synchronous Ethernet timing networks

A. SDH timing network

A timing architecture in the SDH digital transmission network is hierarchical, thus every network node has its specific frequency, respectively timing accuracy. This architecture is splitted into 4 layers with strictly defined timing accuracies [5]. Individual SDH timing network elements include build-in frequency generators with the certain accuracy that is not absolutely identical for all elements. Deviations from the nominal synchronization frequency transmitted from node to node are summed and, in consequence, the crash of synchronization can come into the existence at the optical transmission path's end. From this reason, a common primary source of the timing signal is established with the highest Stratum 1 accuracy in the hierarchical structure [5].

A structure of timing elements in the SDH network is hierarchical, defined as the master-slave structure. A basic arrangement is the synchronizing chain, where at the highest level is presented by the PRC (Primary Reference Clock) clock. The second level below is formed by the SSU (Synchronization Supply Unit) clock. The SEC (Synchronous Equipment Clock) clock on the lowest level with the minimum accuracy demand is located in individual SDH timing network elements. According to ITU-T recommendations, the maximum number of elements coupled in the synchronizing chain is defined as

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follows: a maximum of 20 SEC elements located between 2 SSU elements, a maximum of 10 SSU elements and 59 SEC elements in the common chain [5], [6]. The ITU-T recommendation [7] describes the functional architecture of transport networks including network synchronization principles for networks that are based on the SDH.

B. Synchronous Ethernet timing network

The Synchronous Ethernet technology is defined in the ITU-T Q13/15 recommendation, where a distribution of timing signals in the SyncE network is specified. The reference timing signal from the PRC clock is distributed in the Synchronous Ethernet network by similar mechanisms as in the SDH network. Above all, a timing signal is separated from information, managing and controlling signals and then is transmitted through the physical layer [8].

The IETF (Internet Engineering Task Force) organization specified the CES (Circuit Emulation Service) element for interconnecting SDH and Synchronous Ethernet timing networks. For correct interoperability and cooperation between these two networks, the CES element is referred to be as the slave and must have the same synchronization features as the SEC one. A maximum number of CES elements in the synchronizing chain is defined 20 [9]. The ITU-T recommendation [7] also includes the application of various mappings.

III. TRANSMISSION FEATURES OF THE OPTICAL TRANSMISSION PATH

A. Attenuation in the optical transmission medium

The attenuation, alternatively the loss, is depending on the wavelength and is composed from scattering, absorption and bending parts. The total attenuation can be calculated using the formula [5]:

$$a = \alpha \cdot L, \tag{1}$$

where a is the attenuation in [dB], α is the specific attenuation in [dB/km] and L represents the optical fiber length in [km]. This attenuation simultaneously corresponds to a difference between the transmitter power and the receiver sensitivity and, therefore, can be used for determination of the maximum transmission distance.

B. Dispersion in the optical transmission medium

The dispersion is composed from three main parts - modal, chromatic and polarization mode. The modal dispersion is due to various track lengths of particular modes and is present in multi-mode optical fibers. In single-mode fibers, the chromatic dispersion depending on the spectral bandwidth of optical sources becomes evident. In these fibers, the polarization mode dispersion is also originating and, therefore, a resultant value is given from contributions of both CD and PMD components [10]. Then, a final time expansion of the transmitted optical impulse is determined. For successful and reliable separation of particular optical impulses, a maximum transmission rate of the digital signal is limited by a following equation:

$$R_b = \frac{1}{T_b}, \tag{2}$$

where R_b is the transmission bit rate in [bit/s] and T_b is the time duration of one information bit in [s]. For correct detecting of the information optical impulse, a maximum of its time expansion is theoretically limited to a half of the time duration of one information bit. For more real approximation, a possible impulse time expansion is set to the $1/10 \cdot T_b$ value in the program.

C. Parameters of used components

A optical transmission path utilizing the optical transmission medium is composed from following components:

- a source of the optical radiation,
- an optical fiber,
- a detector of the optical radiation.

Concrete values related to the source power, the specific attenuation and dispersion of the optical fiber and the receiver sensitivity used in the created evaluation program can be found in [11]–[16].

IV. THE EVALUATION PROGRAM

The core of this contribution is an evaluation program for analyzing influences of the optical transmission medium on timing signals transmitted by hybrid transport technologies through evaluating transmission parameters. It is created by using the MatLab programming environment.

In timing networks, we can distinguish 4 basic types of the synchronization clock (Type I – IV) that are determined by their accuracy (in a time and/or frequency domain). These four synchronization clocks are organized in the hierarchical timing structure where the strongest requirements are defined for the highest level related to the PRC. The Primary Reference Clock represents the Type I clock. For this reason, it is satisfactory to focus our attention only on the Type I level. Other clocks located on lower levels are constrained with less rigorous demands. The Appendix III in [7] contains concrete guidelines for synchronization network engineering where all aspects related to the arrangement of synchronization clocks are explained by detail. For timing signals transmitted in the optical transmission medium, it is important to specify a concrete carrier wavelength of the optical radiation. For selecting adequate sources of the optical radiation, these specific source wavelengths together with their spectral bandwidth (deviations) are important.

For the Type I clock, a defined maximum deviation for the timing signal is 1,5 nm modulated at the source wavelength. Typical utilized source of the optical radiation in practical transmission systems has a broader defined minimum spectral bandwidth [11]. Because a bandwidth of the modulated timing signal is included in this minimum spectral bandwidth, the Type I clock timing signal is not necessary to adapt for transmitting through the optical medium. Hereby, it is satisfactory to consider only mentioned source spectral bandwidth in the evaluation program.

A. Graphical interface

After running the program, the opening screen is displayed (Fig. 1).

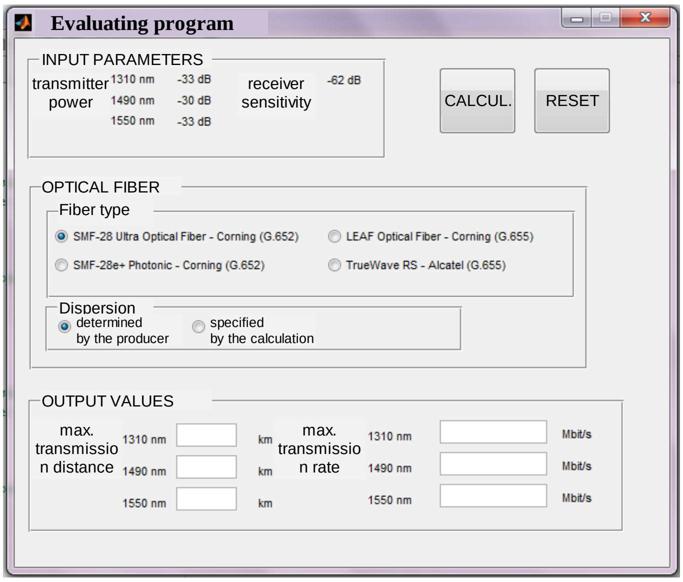

Fig. 1: The graphical interface of the evaluation program

In the first evaluation step, parameters for the source and the detector of the optical radiation are presented. Consequently, using input values of the transmitter power P_{tran} in [dB] and the receiver sensitivity S_{rec} in [dB] together with the specific attenuation value α_{OF} in [dB/km] for the selected fiber type, a calculation can be executed for defined wavelengths. A maximum transmission distance L of the optical path transmission can be calculated using a following formula resulting from the formula (1):

$$L = \frac{1}{\alpha_{OF}} \left(10 \cdot \log \frac{P_{trans}}{S_{rec}} \right), \qquad (3)$$

In the evaluation program, considered optical fibers are presented. In the part “Fiber type”, 4 considered kinds of optical fibers are included - two are based on the ITU-T G.652 standard [17] and two on the ITU-T G.655 standard [18]. Parameters of these fiber types are used in both evaluation steps by appropriate way. As a default choice, the Corning SMF-28 Ultra optical fiber and values determined by the producer are predetermined.

In the second evaluation step, an approach for dispersion calculating must be selected. There come into consideration two choices - concrete values determined by the producer or values considering the spectral bandwidth of the source. Using obtained values of the chromatic dispersion D_{CH} in [ps/(nm.km)]] for the selected fiber type and the source spectral bandwidth BW_{source} in [nm] together with the calculated maximum transmission distance L, a calculation can be executed for defined wavelengths. A transmission rate R_b of the optical information signal can be calculated using following formulas resulting from the formula (2):

$$\Delta t_{CH} = \frac{D_{CH}}{BW_{source} \cdot L}, \qquad (4)$$

$$R_b = \frac{1}{10 \cdot \Delta t_{CH}}, \qquad (5)$$

where Δt_{CH} is the impulse time expansion in [ps] due to the chromatic expansion of optical fibers.

Finally, output values of the evaluation are presented. Here, the maximum transmission distance L [km] of the optical radiation together with the maximum transmission rate R_b [Mbit/s] of the information signal are displayed for particular source wavelengths.

B. Resultant values for the maximum transmission distance and transmission rates

Resultant values of the maximum transmission distance L and transmission rates $R_{b\ det}$ and $R_{b\ func}$ for Corning SMF-28 Ultra and Corning SMF-28e+ Photonic optical fibers are introduced in Tables I and II. The transmission rate $R_{b\ det}$ is calculated based on values determined by the producer, the transmission rate $R_{b\ func}$ is calculated from functionally dependent values on wavelengths for the specific attenuation and chromatic dispersion.

TABLE I
RESULTANT VALUES FOR THE CORNING SMF-28 ULTRA OPTICAL FIBER

λ [nm]	L [km]	$R_{b\ det}$ [Mbit/s]	$R_{b\ func}$ [Mbit/s]
1310	82,8571	109 858,8	18,3291
1490	160,000	79 056,9	7,4452
1550	145,000	0,9576	0,8900

TABLE II
RESULTANT VALUES FOR THE CORNING SMF-28E+ PHOTONIC OPTICAL FIBER

λ [nm]	L [km]	$R_{b\ det}$ [Mbit/s]	$R_{b\ func}$ [Mbit/s]
1310	82,8571	109 858,8	16,7498
1490	133,333	86 602,5	9,3439
1550	145,000	0,9576	0,9687

The Corning SMF-28 Ultra and Photonic optical fibers correspond to the ITU-T G.652 standard [17]. They present classical single-mode fibers used in telecommunications. The zero value of the chromatic dispersion is located around the 1310 nm wavelength, where the maximum achievable rate $R_{b\ det}$ approximately 100 Gbit/s is resulting. When a spectral bandwidth of the optical source is considering together with a functional dependency on wavelengths for the chromatic dispersion, a theoretical maximum achievable rate $R_{b\ func}$ is decreased to tens of Mbit/s. A value of the chromatic dispersion determined by the producer at the 1550 nm wavelength is approximately the same as a functionally dependent value, therefore maximum achievable transmission rates are roughly equal for both cases.

A specific attenuation of the SMF-28 Ultra optical fiber has the lowest value at the 1490 nm wavelength. It means that the longest transmission distance L can be reached exactly at this wavelength. For this case, however, a transmission rate is decreased due to the signal transmission over this distance. The lowest value of the specific attenuation for the SMF-28e+ Photonic optical fiber is present at the 1550 nm wavelength; hence a signal travels the longest transmission distance at this wavelength for given fiber.

Resultant values of the maximum transmission distance L and transmission rates $R_{b\ det}$ and $R_{b\ func}$ for Corning LEAF and Alcatel Lucent TrueWave RS optical fibers are introduced in Tables III and IV.

TABLE III
RESULTANT VALUES FOR THE CORNING LEAF OPTICAL FIBER

λ [nm]	L [km]	$R_{b\ det}$ [Mbit/s]	$R_{b\ func}$ [Mbit/s]
1310	85,2941	12,4349	11,0904
1490	145,4545	23,2488	23,0484
1550	138,0952	4,5259	2,9817

TABLE IV
RESULTANT VALUES FOR THE ALCATEL LUCENT TRUEWAVE RS OPTICAL FIBER

λ [nm]	L [km]	$R_{b\ det}$ [Mbit/s]	$R_{b\ func}$ [Mbit/s]
1310	72,5000	3,8314	3,3642
1490	106,6667	69,4444	64,1026
1550	116,0000	3,5920	2,9727

The Corning LEAF and Alcatel Lucent TrueWave RS optical fibers correspond to the ITU-T G.655 standard [18]. They present optical fibers with the shifted zero value of the chromatic dispersion to the 1550 nm wavelength surroundings. For both kinds, the producer determined a functional dependency of the chromatic dispersion on wavelengths. Therefore, values of the maximum theoretical transmission rates are approximately equal in both cases. Both optical fibers reach the maximum transmission rates around the 1490 nm wavelength. The TrueWave RS optical fiber reaches higher transmission rate at this wavelength, however a signal travels shorter transmission distances compared with the LEAF optical fibers. From calculated values, we can consider that the TrueWave RS directional vector forms a bigger angle with the horizontal axis than the LEAF one for about linear functional dependencies on wavelengths for the chromatic dispersion.

In practice, results from the evaluation program can be used in different ways, for instance at a selection of the wavelength for the optical channel with given transmission rates, respectively at a determination of the transmission rate for selected wavelengths. Just as well, a specifying of the source working wavelength for the longest transmission distance on the optical fiber's parameters can be realized based on presented resultant values. Globally, the presented evaluation program with analyzing of specific optical fibers can be utilized for evaluation of exploited optical transmission paths transmitting digital signals. In consequence, applicability and benefits of the optical transmission medium for transmitting timing signals for developed future services and applications and global telecommunication networks can be determined.

V. CONCLUSION

The program for analyzing influences of the optical transmission medium on timing signals transmitted by hybrid transport technologies through evaluating transmission parameters is created and related to a synchronization in SDH and Synchronous Ethernet timing networks.

A timing signal travelling through the optical fiber is influenced by various negative environmental effects. To the most expressive ones belong an attenuation and a dispersion, therefore it is important to know exact values for these parameters and/or exact functional dependencies on wavelengths for given parameters. From this reason, a timing signal is travelling through the optical transmission path with a finite transmission rate on a definite transmission distance. Results from the evaluation program prove that there can be found marked differences based on approaches to the dispersion characteristics for some types of optical fibers. These differences can lead to significant problems at the practical realization of multiple optical channel transmissions in hybrid transport systems using a wavelength division multiplexing technique.

The created evaluation program satisfies essential demands for determination a maximum transmission distance and a maximum transmission rate of timing signals transmitted through the optical transmission path. The program is created in the MatLab programming environment with a simple and comprehensible graphical interface. In a near future, possibilities for selecting of source, optical fibers and detectors can be easily extended. Moreover, other optical components (namely connectors, couplers, welds, …) utilized in conjunction with the optical fiber can be included for analyzing influences of the optical transmission medium on timing signals.

In the next phase, an influence of network nodes included in the optical transmission path will be analyzed. For this intention, two direction of research are considered. First, network nodes realized with electro-optical and opto-electrical conversions will be supposed. Second, network nodes with only optical processing and controlling of timing signals are assumed.

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