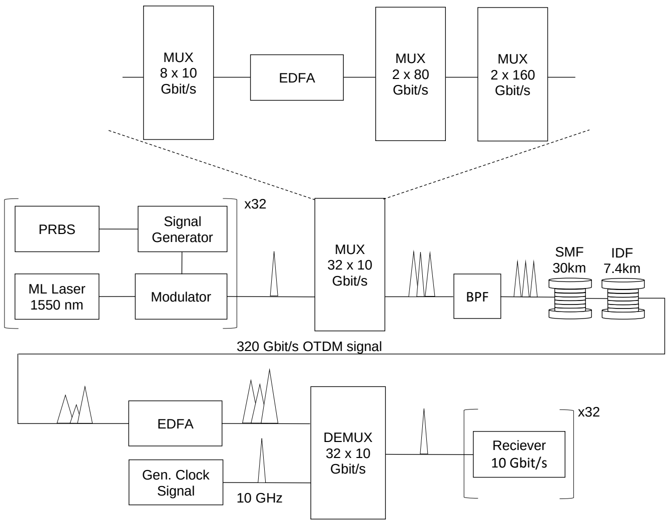

Fig. 3. Block scheme of the 320 Gbit/s OTDM network.

$$\Delta\lambda = \frac{\lambda^2 \times K}{\Delta t \times c_0}. \quad (1)$$

where $\Delta\lambda$ is the spectrum FWHM of a signal, Δt is the temporal FWHM of investigated signal, c_0 represents the speed of the light in vacuum, λ is the wavelength and K is Time-Bandwidth-Product [10]:

$$K = \Delta\lambda \times \Delta t \quad (2)$$

when $K = 0.4413$ for the Gauss pulse shape and $K = 0.3148$ for the Sech pulse shape.

V. Simulation set-up

The experimental set-up is shown in Fig. 3. A block scheme of the simulation model can be divided into three parts (transmitter, distribution part and receiver). To make simulation model realistic attenuaters and Erbium Doped Fiber Amplifiers (EDFAs) are installed. The simulation was performed in the OptSim software from RSoft Design Group [14].

The transmitter includes a 10 GHz MLFL laser as a source of 3.13 ps very short pulses at 1550 nm. The short pulses are modulated by a Mach-Zehnder Modulator (MZM) with a PRBS word length of $2^7 - 1$. The 10 Gbit/s modulated signal is multiplexed to 320 Gbit/s by the OTDM fiber-delay multiplexer. The 320 Gbit/s modulated signal passes through the BPF, which is set to 4 nm.

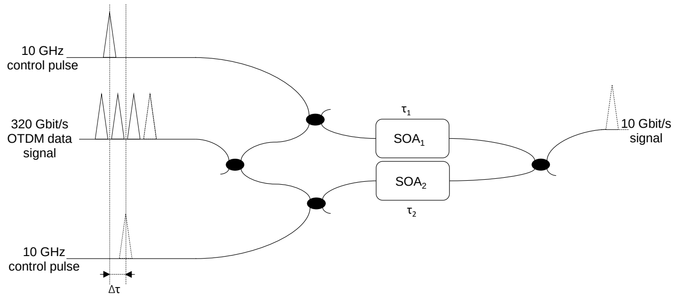

Fig. 5. The principle of the TOAD based on SMZ.

The distribution part consists of a 30 km Single Mode Fiber (SMF), compensated by 7.4 km of the IDF. A total dispersion slope of SMF is 0.9×10^3 s/m^3 and of IDF is -0.359×10^3 s/m^3.

In the receiver part, the 320 Gbit/s signal is first amplified in EDFA and then demultiplexed to 10 Gbit/s by Symmetric Mach-Zehnder (SMZ) interferometer using Semiconductor Optical Amplifier (SOA). The most important part of SMZ is the 10 GHz control signal demarcation which is after for of the data signal. Time delay between two control pulses is realized by an optical splitter 1:2, and by two time-delay units realized in the simulation model.

The principle description of the Terahertz Optical Asymmetric Demultiplexer (TOAD) based on SMZ is in literature [2], [11], [12] and is shown in Fig. 5. The 10 Gbit/s demultiplexed signal passes through a polarization filter and is analyzed by the BER analyser.

VI. Results

A. The modulation formats simulation

Fig. 4 a), b), and c) show the wavelength spectrum of NRZ, CSRZ and 4-QAM with a bitrate of 320 Gbit/s multiplexed OTDM signals. Measurements were performed after pass through BPF. BPF must be used before the signal passes through the 30 km optical line and the 7.4 km IDF. This ensures the better results of transmission, especially reduction the BER.

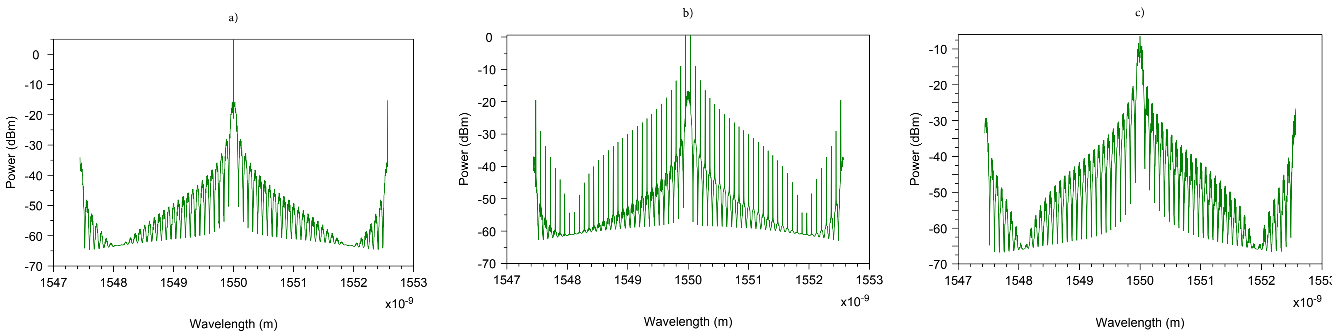

Fig. 4. The wavelength spectrum of a 320 Gbit/s OTDM signals for the a) NRZ, b) CSRZ, and c) 4-QAM formats.

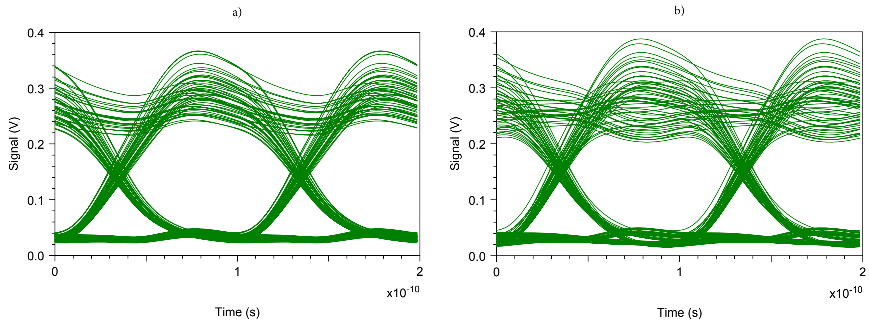

Fig. 6. Eye diagrams for a) NRZ, b) CSRZ, and c) 4-QAM

In Fig. 6 we can see eye diagrams at the end of SMZ TOAD. Different shapes of the eye diagrams demonstrate the differences between basic modulation formats and the 4-QAM modulation. It is caused by a number of transmitted states in individual modulations.

For all 320 Gbit/s OTDM systems except the CSRZ, BER of less than 10^{-9} was obtained. The RZ, NRZ, and CRZ modulation formats have narrower central lobe. It is a prerequisite for using in high transmission OTDM systems.

The BER values of all tested modulations are presented in Fig. 7. From Fig. 7 we can see they acceptable results are for the RZ, NRZ, and CRZ modulation formats having BER exceeding 2.00×10^{-13}, eventually 4-QAM having BER 2.10×10^{-10}.

B. The IDF simulation

The IDF has a positive influence on the total BER. Optimal length of IDF was selected based on BER, the results are shown in Fig. 8. Distribution path has the best parameters while using IDF of a length between 7.2 and 7.4 km. When IDF of a length 7.6 km is used, the value of BER is improvement of $> 30\,\%$.

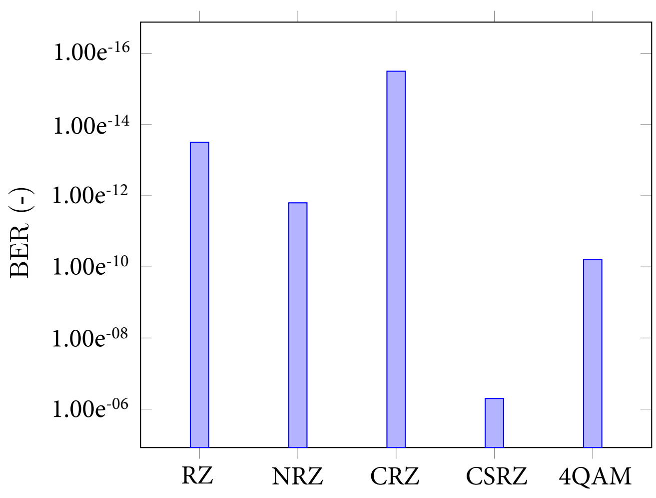

Fig. 7. Comparison of all modulation formats used in the simulation.

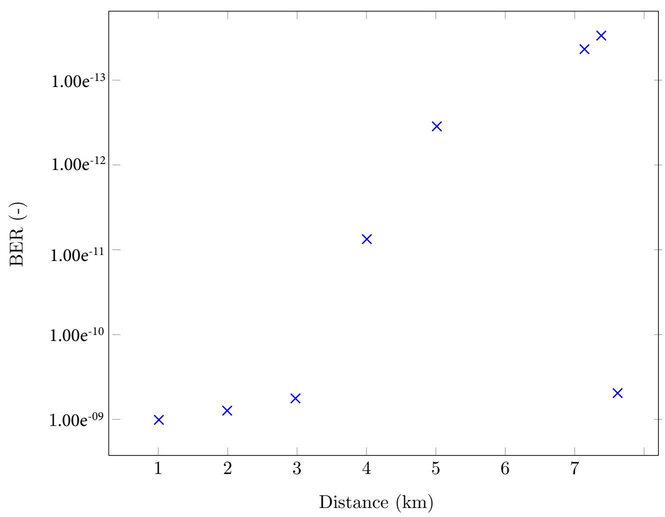

Fig. 8. The effect of size BER on the length of the IDF, while using the RZ modulation format.

VII. Conclusion

In this article we demonstrated influence of modulation formats on the 320 Gbit/s OTDM transmission system over 30 km of SMF and 7.4 km of IDF. From our results it is evident that CRZ modulation format is a suitable choice for using in the 320 Gbit/s OTDM optical communications. On the other hand, the CSRZ modulation format is not suitable for the OTDM systems. In the simulation models Forward Error Correction (FEC) is not used. In addition using IDF may have a huge impact on the OTDM system. The future research would focus on an application of multitone modulation formats, application of FEC, extension of distribution path, and increasing the of bit rate to 640 Gbit/s and higher.

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