doi:10.20944/preprints201909.0031.v1

Nonlinearities Diminution in 40 Gb/s 256 QAM Radio over Fiber Link via Machine Learning Method

Muhammad Usman Hadi[1]
[1]Department of Electronic and Information Engineering, University of Bologna, Italy.

Machine learning (ML) methodologies have been looked upon recently as a potential candidate for mitigating nonlinearity issues in optical communications. In this paper, we experimentally demonstrate a 40-Gb/s 256-quadrature amplitude modulation (QAM) signal-based Radio over Fiber (RoF) system for 50 km of standard single mode fiber length which utilizes support vector machine (SVM) decision method to indicate an effective nonlinearity mitigation. The influence of different impairments in the system is evaluated that includes the influences of Mach-Zehnder Modulator nonlinearities, in-phase and quadrature phase skew of the modulator. By utilizing SVM, the results demonstrated in terms of bit error rate and eye linearity suggest that impairments are significantly reduced and licit input signal power span of 5dBs is enlarged to 15 dBs.

Keywords: Radio over Fiber, Nonlinearities Mitigation, Support Vector Machine method

Corresponding author: M. U. Hadi;
email: usmanhadi@ieee.org; muhammadusman.hadi2@unibo.it

I. INTRODUCTION

Analog Radio over Fiber (A-RoF) links are meant to meet the ever-increasing requirements of wireless distribution services from the base station (BS) to remote antenna heads (RAH). The deployment of A-RoF has been seen in different scenarios ranging from inhouse to outdoor applicative scenarios [1-4]. Since, A-RoF systems can serve as a block for cloud radio access network (C-RAN) which connects the base band units (BBU) to remote radio heads (RRHs). The interlinking of these BBUs with RRHs through distribution network is referred as the ‘fronthaul’ [5]. A-RoF is a good candidate for such fronthaul applications.

However, A-RoF technology is prone to nonlinearities that occur due to physical properties of laser, fiber and photodiode in the link [6,7]. Similarly, A-RoF transmission is dependent on optical subcarrier modulation techniques which suggests the use of orthogonal frequency divisional multiplexing (OFDM) that have high peak to average power ratio (PAPR) [8]. Therefore, these A-RoF links are prone to impairments.

The mollification of nonlinearities has gained immense importance to increase the optical system capacity. Many impairment mitigation methods have been proposed that includes the linearization based on Digital Predistortion [10-13]. Direct Digital Predistortion technique

(DPDT) that linearizes the links by realizing the behavioral model of A-RoF links was also proposed in [6,13]. However, these linearization techniques are complex, time consuming and adds extra over heads [14-18]. Therefore. mitigating such nonlinearities in A-RoF links effectively is still an open-ended question.

The use of machine learning (ML) based classifiers for nonlinear mitigation in A-RoF is comparably new concept in the optical communications. Recently, in past few years, the use of ML techniques to optical communication system has given an innovative direction. ML can be employed to explicitly describe the challenges in optical fiber communications [19,20] such as performance optimization, testing, planning and equipment realization. Use of ML-based algorithms for mitigating the nonlinearities of radio over fiber system is a unique concept that should be investigated in detail. In general, these methods learn from the properties of various nonlinear impairments through the applied models which can be utilized for either compensation and quantification of impairments introduced.

Machine learning methodologies such as K nearest neighbor algorithms (KNN), artificial neural networks (ANN) and support vector machines (SVM) are widely used in channel monitoring, modulation format identification, nonlinear compensation, equalization and demodulation [21-22].

ML based methods can partially mitigate the fiber nonlinearities and noise interactions. Similarly, the information of optical link is not required apriori. Therefore, these reasons tend to make them a good choice for optical networks where dynamic tracking and compensation of link and channel impairments is needed.

In this paper, the mitigation of nonlinear impairments is experimentally evaluated by employing SVM based machine learning methods. In the proposed system, 40-Gb/s with 256 quadrature amplitude modulation (QAM) signal is injected into distributed feedback (DFB) laser for 50 km single mode fiber transmission. It causes signal to suffer from nonlinearities due to opto-electronic devices in the RoF link as the ideal decision boundary is no longer linear. The utilization of SVM method is compared with the case without the use of SVM to mitigate the nonlinearities of the RoF system.

II. Experimental Setup

The experimental setup utilized is demonstrated in Fig. 1. The arbitrary waveform generator (AWG) operating at 40-GSamples/s drives the in-phase and quadrature (I/Q) Mach–Zehnder modulator (MZM), whose I & Q port are quadrature point biased while Q port has a $\frac{\pi}{2}$ phase difference. The signal baud rate is 10 GBd which means that up sampling is required at four samples per symbol. The modulated 256-QAM signal is used while the laser diode (LD) is working at 1550 nm. The Single Mode Fiber (SMF) of 50 km length is followed by variable optical attenuator referred as VOA whose functionality is to adjust the received optical power. The signal is photo detected by a photodiode having 0.7 A/W of responsivity and 9.6 GHz bandwidth. Then, the signal is passed through the digital processing block for machine learning decisions in offline manner. Here, the SVM is utilized that finds the optimum decision boundary. Minimal optimization algorithm is used to find the boundary condition while the training threshold is at about 5.1% with 1400 symbols to automatically obtain the optimal parameters. Finally, after this adjustment, parameter evaluation is done and compared to see if SVM based ML method is improving the performances of the RoF link considered or not.

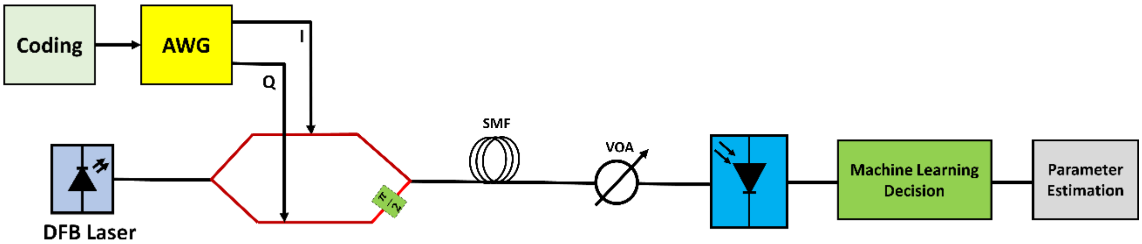

Fig. 1. Experimental setup. AWG: Arbitrary Waveform Generator, DFB laser: Distributed Feedback laser, MZM: Mach-Zehnder Modulator, VOA: Variable Optical Attenuator, SMF: Single Mode Fiber

The steps involved in SVM implementation are as follows:

1. Firstly, the data is transmitted synchronously to each of the SVM.
2. The parametric optimization is performed for seven SVM classifiers.
3. The labelled data with original data is compared to calculate the error bits.

Let's take into consideration 10001100 as a constellation data received for SVM decision. Primarily, the signal data is transferred to the first SVM where the primary bit ‘‘1’’ is labelled as ‘‘1’’ by SVM1 decision. Then, it is forwarded to SVM2 and the 2nd bit ‘‘0’’ is labelled as ‘‘-1’’. Finally, the test data is sent to SVM3, SVM4 and SVM5, SVM6 where the 3rd , 4th , 5th and 6th bits are labelled as ‘‘−1’’, ‘‘−1’’ and ‘‘+1’’ and “-1”, sequentially.
Eventually, SVM7 and SVM 8 receives the data and it classifies the seventh and eight bit ‘‘0’’ as ‘‘-1’’. Once all the test data are filled, the BER of eight bits are recalculated. Consequently, a correct decision can be made by eight SVMs for all constellation points of 256-QAM signal.

III. Experimental Results and Discussion

The experimental results are discussed in this section where SVM based method is compared with respect to the case where no SVM is used for mitigating nonlinearities. Fig. 2 represents the bit error rate (BER) versus number of training data points. It can be seen that BER for SVM. When the number of training data is larger than 4000, SVM saturates the improvement in performance.

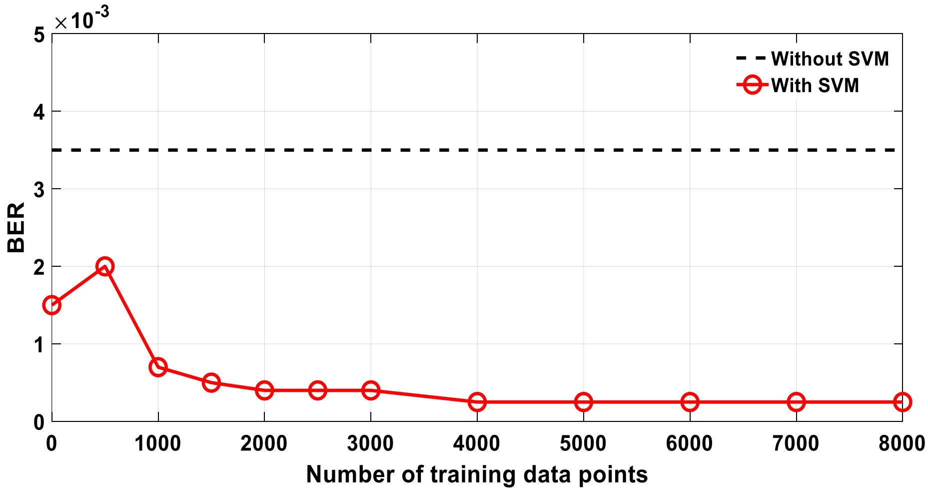

Fig. 2. BER vs number of training data points for SVM compared with no SVM implied

doi:10.20944/preprints201909.0031.v1

Similarly, the modulator attributes are evaluated in Fig. 3 as the I/Q skew phase has ability to demean the system efficiency, represented with black dashed line in Fig. 3. The automatic bias controller (ABC) present in the system doesn not accurately adjusts the I/Q phase. Therefore, it becomes a matter of critical importance to compensate the system with SVM method. It can be seen that with the SVM classifier algorithm, the I/Q phase skew variations are decreased due to which BER is decreased significantly. It is visible that system impairments due to amplified spontaneous emission (ASE), modulator nonlinearity, I/Q phase skew, etc can be decreased notably using the proposed method.

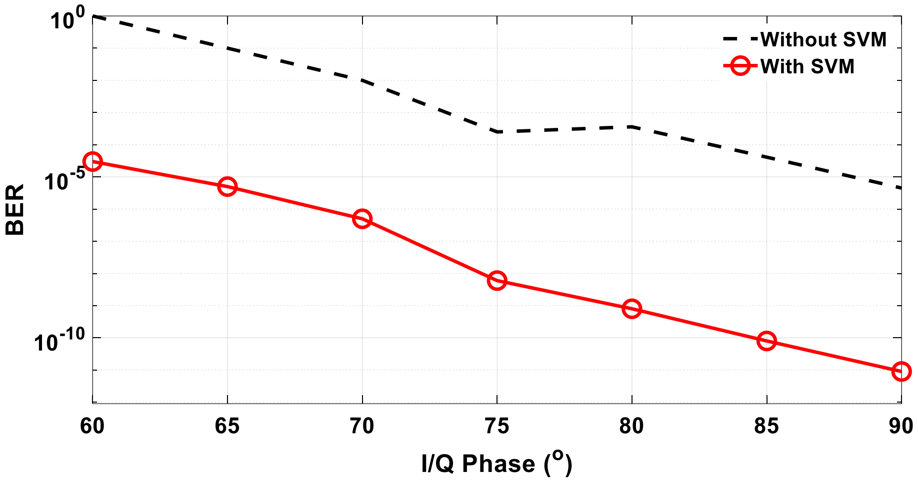

Fig. 3. BER vs I/Q phase skew comparison with and without SVM

In order to see the influence of the modulation index of MZM on the BER of the system, the modulation amplitude is varied in Fig. 4. In this case, the amplitude is varied from 0.1 to 0.9 while keeping the input power fixed to -16 dBm. From the results, the SVM decision can improve the BER performance with varying amplitude.

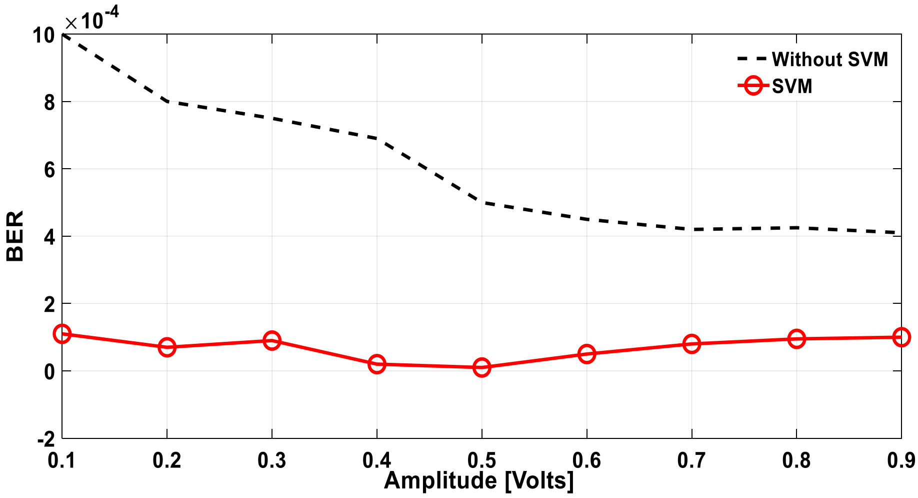

Fig. 4. BER vs amplitude of the MZM driver with and without SVM

Finally, BER is shown with respect to RF input power which goes inside the 50 km fiber. By increasing the input power, the optical signal to noise ratio (OSNR) of the signal received is prohibitively large that results in a higher BER. Thus, the signal experiences severe amplified-spontaneous emission (ASE) noise. When the input power increases from a value, the BER rate is perished by fiber Kerr nonlinearity. However, with SVM, these impairments are reduced significantly. The trend can be seen in Fig. 5 that range of input power is widened from 5 dB (-5 dBm to 0 dBm, no SVM case) to 15 dBs (-10 dBm to 5 dBm) with SVM use.

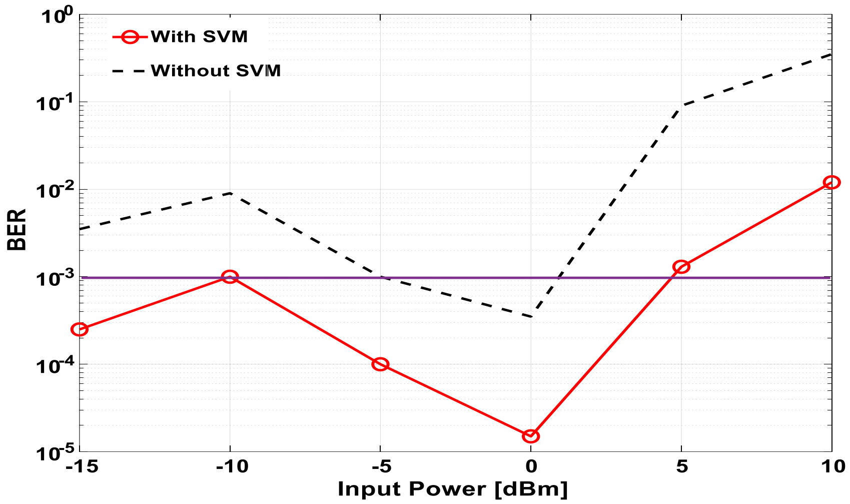

Fig. 5. BER vs launched input signal power for SVM compared with and without SVM.

BER performance at 50 km for different parameters are recapped in Table 1 below:

Evaluated Parameter	BER Without SVM	BER With SVM
P_{IN}@ 0 dBm	$3.5\text{x}10^{-4}$	$1.51\text{x}10^{-5}$
I/Q phase Skew @ 65°	0.1	$5\text{x}10^{-6}$

Table 1. Summary of BER with and without SVM

IV. CONCLUSION

The article demonstrated experimentally SVM signal decision approach for mitigating the nonlinearities in RoF system. The experimental results show that for a complex and high modulation format of 256 QAM at 50 km of fiber length, SVM results in significant reduction of the bit error rate in considered RoF system. Similarly, the modulator I/Q phase skew degradation in terms of BER at 65° is reduced from 0.1 to a relative lower value of $5\text{x}10^{-6}$. Similarly, the SVM application allows to widen the admissible input power range from 5 dBs to 15 dBs. The future work includes the simplification of algorithm for SVM implementation and envisages the use of other classifiers that can alleviate the impairments in the RoF system.

REFERENCES

[1] D.Visani, G Tartarini, M.N Petersen, L Tarlazzi, P Faccin, “Link design rules for cost-effective short-range radio over multimode fiber systems”, IEEE Transactions on Microwave Theory and Techniques 58 (11), 3144-3153

[2] Tartarini, G. and Faccin, P. (2005), Efficient characterization of harmonic and intermodulation distortion effects in dispersive radio over fiber systems with direct laser modulation. Microw. Opt. Technol. Lett., 46: 114-117. doi:10.1002/mop.20917

[3] D. Visani et al., "Wired and wireless multi-service transmission over 1mm-core GI-POF for in-home networks," in Electronics Letters, vol. 47, no. 3, pp. 203-205, 3 February 2011. doi: 10.1049/el.2010.7273

[4] Y. Shi et al., "First demonstration of HD video distribution over large-core POF employing UWB for in-home networks," 2011 Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference, Los Angeles, CA, 2011, pp. 1-3.

[5] Muhammad Usman Hadi, Hyun Jung, Salman Ghaffar, Pier Andrea Traverso, Giovanni Tartarini, Optimized digital radio over fiber system for medium range communication, Optics Communications, Volume 443, 2019, Pages 177-185, ISSN 0030-4018, https://doi.org/10.1016/j.optcom.2019.03.037.

[6] Hadi, M.U., Nanni, J., Polleux, JL. et al. Opt Quant Electron (2019) 51: 205. https://doi.org/10.1007/s11082-019-1923-8

[7] M. U. Hadi, "Extending the benefits of LTE to unlicensed spectrum," 2015 International Conference on Information and Communication Technologies (ICICT), Karachi, 2015, pp. 1-3. doi: 10.1109/ICICT.2015.7469592

[8] Roselli, L., Borgioni, V., Zepparelli, F., Ambrosi, F., Comez, M., Faccin, P., Casini, A.: Analog laser predistortion for multiservice radio-over-fiber systems. IEEE J. Lightwave Technol. 37(5), 1211–1223 (2003)

[9] M. U. Hadi et al., "Experimental evaluation of digital predistortion for VCSEL-SSMF-based Radio-over-Fiber link," 2018 International Topical Meeting on Microwave Photonics (MWP), Toulouse, 2018, pp. 1-4.doi: 10.1109/MWP.2018.8552895

[10] M. U. Hadi, P. A. Traverso, G. Tartarini, O. Venard, G. Baudoin and J. Polleux, "Digital Predistortion for Linearity Improvement of VCSEL-SSMF-Based Radio-Over-Fiber Links," in IEEE Microwave and Wireless Components Letters. doi: 10.1109/LMWC.2018.2889004

[11] Hadi, M.U., Nanni, J., Traverso, P.A., Tartarini, G., Venard, O., Baudoin, G., Polleux, J.L.: Linearity improvement of VCSELs based radio over fiber systems utilizing digital predistortion. Adv. Sci. Technol. Eng. Syst. J. 4(3), 156–163 (2019). doi: 10.25046/aj040321

[12] Hekkala A, Hiivala M, Lasanen M, Perttu J, Vieira LC, Gomes NJ, et al. Predistortion of radio over fiber links: algorithms, implementation, and measurements. IEEE Trans Circuits Syst I Regul Pap. 2012;59:664–72.

[13] F. Fuochi, M.U. Hadi, J. Nanni, P.A. Traverso, G. Tartarini, "Digital predistortion technique for the compensation of nonlinear effects in radio over fiber links", 2016 IEEE 2nd

International Forum on Research and Technologies for Society and Industry Leveraging a better tomorrow (RTSI), pp. 1-6, 2016

[14] Hadi, M., Jung, H., Traverso, P., et al. (2019). Digital Radio Frequency Transport over Optical Fiber for 5G Fronthaul Links. Journal of Optical Communications, doi:10.1515/joc-2019-0051

[15] Hadi M, Aslam N, Jung H. (2019). Performance appraisal of sigma delta modulated radio over fiber system. Journal of Optical Communications, doi:10.1515/joc-2018-0227.

[16] Hadi, M., Hadi, M., Aslam, N., et al. (2019). Experimental Demonstration of MASH Based Sigma Delta Radio over Fiber System for 5G C-RAN Downlink. Journal of Optical Communications, doi:10.1515/joc-2019-0011

[17] Muhammad Usman Hadi, Pier Andrea Traverso, Giovanni Tartarini, Hyun Jung, Experimental characterization of Sigma Delta Radio over fiber system for 5G C-RAN downlink, ICT Express, 2019, ISSN 2405-9595, https://doi.org/10.1016/j.icte.2019.06.002.

[18] Ranaweera C, Wong E, Nirmalathas A, Jayasundara C, Lim C. 5G C-RAN with optical fronthaul: an analysis from a deployment perspective. J Lightw Technol. 2018;36:2059–68.

[19] D. Zibar, M. Piels, R. Jones and C. G. Schäeffer, "Machine Learning Techniques in Optical Communication," in Journal of Lightwave Technology, vol. 34, no. 6, pp. 1442-1452, 15 March15, 2016.doi: 10.1109/JLT.2015.2508502

[20] G. Chen, J. Du, L. Sun, et al. “Nonlinear Distortion Mitigation by Machine learning of SVM classification for PAM-4 and PAM-8 modulated optical interconnection,” J. Lightw. Technol., vol. 36, no. 3, pp. 650–657, 2018.

[21] L. Sun, J. Du, Z. He. “Machine learning for nonlinearity mitigation in CAP modulated optical interconnect system by using K-nearest neighbor algorithm,” Proc. ACPC 2016, AS1B.1.

[22] D. Wang, M. Zhang, Z. Li, et al. “Nonlinear decision boundary created by a machine learning-based classifier to mitigate nonlinear phase noise,” ECOC 2015, paper 0720.