100Gb/s/λ IM-DD PON using 20G-class optical devices by machine learning based equalization

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Abstract We propose the novel machine learning based equalization algorithm for IM-DD PON and extend the capacity of PON from 50Gbps/λ to 100Gbps/λ. 100Gb/s PAM8/PAM16 IM-DD transmission is achieved over 25km SSMF using 20G-class optics.

Introduction Nowadays, there are many applications and market-demanding factors driving the need for higher-speed access network, such as the rapid growth of the high-definition video streaming services, the burst of smart devices of Internet of Things (IoT) and the development of wireless backhaul of 5G 1. Currently standard groups like IEEE 802.3ca and ITU-T SG15 are working on their 50Gbps/λ passive optical network (PON) industry standard, aiming at deployment in the next few years. Besides, several feasible 50Gbps/λ solutions have been proposed during the past several years. Due to the nature requirement of low cost in PON, optics with limited bandwidth, advanced modulation formats and advanced equalization algorithms are widely chosen as the main research topic of 50Gbps/λ PON. Algorithms like feed-forward equalization, maximum likelihood sequence estimation, volterra nonlinear equalization and machine learning based equalization algorithm have been investigated to overcome the limitation of channel impairment 2-4. To further increase the loss budget, some optical architectures have also been introduced such as dispersion shifted fiber (DSF) and semiconductor optical amplifier (SOA) 5-7. Based on our proposed machine learning based equalization technique, we have also realized 50Gb/s PON with 29-dB loss budget8.

While the research and standardization of 50Gb/s/λ are steadily progressing, we decide to push the limits and pay more attentions to the next step 100Gbps/λ research. In the intensity modulation and direct detection (IM-DD) community, there is a solid foundation of 100Gbps transmission, and we have also made some attempts based on our proposed machine learning based equalization technique 9.

In this paper, we introduce the novel machine learning based equalization for high-speed PON applications and show the experimental demonstration of 50Gb/s IM-DD PON based on 10G-class optics and 100Gb/s IM-DD PON based on 20G-class optics.
After the optical channel, the signal is digitally sampled by the DSO, then the offline digital signal processing is performed to evaluate the system performance. As shown in Fig. 2(b), the total 3-dB channel bandwidth is 6 GHz. The eye diagrams of electrical back-to-back, optical back-to-back and 25-km transmission can also be found in Fig. 2.

Figure 3 shows the BER performance of different equalization algorithms under the condition of the experimental setup. Different configuration of FFE, volterra nonlinear equalizer are tested. With the help of our proposed machine learning based equalizer, receiver sensitivity of -19.2 dBm is achieved for optical back-to-back and 25km SSMF transmission. Considering 10-dBm output of the DML, total loss budget of 29.2dB is achieved.

**100Gb/s IM-DD PON based on Machine Learning**

We further evaluated the performance of our proposed machine learning based equalization for 100Gb/s IM-DD PON applications. The network structure is shown in Fig. 4.

Comparing to the previous network setup, one more linear layer is added to the network to increase the total network learning capability. What's more, the output layer is adjusted to 8 or 16 based on whether PAM8 or PAM16 is transmitted. The network is trained using mini-batch gradient descent with a batch size of 512, which take the advantage of the parallel computing capability of GPU and largely accelerate the training process. In addition, dropout with p=0.1 is also introduced to deal with the over-fitting problem. The dataset is composed of 10 independent PRBS15 receiving symbols, divided in a ratio of 6:2:2 for training, cross validation and testing.

The experimental setup can be found in Fig. 5. The 33GBd PAM8 and 25GBd PAM16 signal are generated by a Keysight 8196A arbitrary waveform generator. Then the signal is
loaded onto light by two different DML in C-band and O-band. After 25km SSMF transmission, a 20G PIN is used to perform the photoelectric conversion. Then the signal is digitized and recorded by the DSO, after which offline DSP is performed.

In this experiment, the loss budget is only around 16 dB considering 10-dBm output power of DML. The loss budget can be improved by using APD and SOA-based pre-amplifier or advanced CNN algorithms with optimized structure, which are under our investigations. In addition, compared with CNN, recurrent neural network (RNN) is more suitable for sequence signals. We will further investigate RNN-based equalization algorithms and its-variants such as reservoir computing for improved performance and reduced complexity.

Conclusions
We propose the novel machine learning based equalization technique based on CNN network and test its performance under the condition of 56Gb/s PAM4 and 100Gb/s PAM8/PAM16 transmission. The algorithm shows its strength in each of the test configurations.

References