obtain 200,000 sample pairs (s_1,s_2). Next, the samples s_1 and s_2 are simply added and an AAH of the resulting samples is generated, which is similar to the AAH obtained using a single PD in MFI module shown in Fig. 5(a). In the event that the modulation format is identified to be RZ-DQPSK or PM-RZ-QPSK, the ANN estimates are subjected to further investigations by comparing the average power $E[s_{1(2)}] = P_{1(2)}$ of the individual samples $s_{1(2)}$. In case of single-polarization RZ-DQPSK signal, the splitting of power in PBS depends upon the relative angle between the signal's SOP and the PBS axis (i.e. $P_1 \neq P_2$ for all relative angles between the signal's SOP and the PBS axis except when the angle is 45°) while the signal power will always split equally in PBS (i.e. $P_1 = P_2$) for PM-RZ-QPSK signal. Hence, if $P_1 \neq P_2$, the modulation format is deduced to be RZ-DQPSK. On the contrary, if $P_1 = P_2$, then this could either (most likely) be a PM-RZ-QPSK signal or an RZ-DQPSK signal with 45° relative angle between the signal's SOP and the PBS axis. In this scenario, the additional polarization information is not conclusive and hence, the estimations made by the ANN-based classifier are taken as the final one. Since the AAHs of RZ-DQPSK and PM-RZ-QPSK formats are significantly different from each other unless when CD and DGD are extremely small, the ANN-based classifier itself can well distinguish between these two modulation formats. Fortunately, the joint occurrence of very small CD and DGD and exactly 45° angle between the signal's SOP and PBS axis (in case of RZ-DQPSK signal) is extremely rare and hence, the modified MFI configuration is able to discriminate between these two modulation formats in most of the cases. The results for the modified MFI configuration exploiting such signal polarization characteristics in addition to using the ANN-based classifier (as shown in Fig. 5(b)) are summarized in Table 2. It is evident from the table that the estimation accuracies for RZ-DQPSK and PM-RZ-QPSK formats have been improved using the modified MFI configuration. The overall estimation accuracy for all six modulation formats is also increased to 99.6%, thus signifying the advantage of the modified MFI configuration. We would like to emphasize that the use of this slightly more sophisticated MFI configuration is beneficial only when both RZ-DQPSK and PM-RZ-QPSK modulation formats are present. For all other scenarios, the simple MFI configuration shown in Fig. 5(a) suffices.

The response time of the proposed MFI technique, which is of vital significance in practical applications, is reasonably small. Using a low-cost sampler with 500 Msamples/s sampling rate, the data acquisition time (which takes a bulk of the whole processing time) for 200,000 samples is 0.4 ms. The subsequent generation of AAH from the acquired samples as well as the estimation of modulation format type using ANN can be done comparatively much faster. Note that the training of ANN may take much longer time but such training is performed offline prior to actual MFI process. Hence, we believe that the whole MFI process using the proposed technique can be completed within a few ms at the most in real network settings. If a further reduction in processing time is desired then this can be accomplished by using more than one asynchronous sampling device for the acquisition of amplitude samples.

4. Conclusions

In this paper, we proposed a low-cost MFI technique for next-generation heterogeneous fiber-optic networks by using an ANN trained with the features extracted from AAHs of the directly detected signals. Numerical simulation results demonstrate over 99% identification accuracy for six widely-used modulation formats for OSNR values as low as 12 dB and also in the presence of various levels of CD and PMD. The proposed technique can effectively enable the MFI feature in future receivers as well as in OPM devices deployed throughout the optical network.

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