A rotated QAM-based probabilistically shaped OFDM with ANN scheme for W-band RoF system

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Abstract: In the paper, a rotated QAM-based probabilistically-shaped (PS) OFDM with artificial neural network (ANN) scheme is proposed in W-band RoF system. After 50-km SSMF and 1-m wireless transmission, the experimental results show that its ROP sensitivity outperforms PS-OFDM.
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1. Introduction

With the increasing demand for high bandwidth and mobility of wireless communication, radio-over-fiber (RoF) is the potential mobile fronthaul technologies. And it serves radio access network (RAN) which connects the base band units (BBU) to remote radio heads (RRHs). Especially, W-band (75~110 GHz) radio shows the high precision and low atmospheric attenuation. Thus, W-band RoF system can enhance the capacity and transmission range of wireless services [1]. Meanwhile, higher-order modulation with orthogonal frequency division multiplexing modulation (OFDM) with time and frequency domain equalization are analyzed and used to improve the performance of RoF system [2]. OFDM and single-carrier modulation are experimentally investigated and compared in W-band RoF system with limited receiver bandwidth [3]. It is proved that, compared with single carrier modulation, OFDM is more suitable for wireless transmission and receiver with limited bandwidth at W-band. In addition, probabilistically shaped (PS) constellation can be utilized in the case of rate adaption and it is considered as the promising technology to close Shannon limit [4]. The generalized mutual information (GMI) of 64QAM PS-OFDM is studied for W-band RoF system [5]. It shows 64QAM PS-OFDM has better performance than uniform 64-QAM, and it has 1.07-dB shaping gain at BER of 10^{-4}. Besides, it states that the advantage of flexible capacity granularity compared with the single-carrier modulation PAS signal. To further improve the capacity, a hybrid time-frequency domain equalization scheme is demonstrated in MIMO PS-OFDM W-band system with coherent detection [6]. It shows that 30 Gbaud OFDM signals with hybrid PS-512QAM and PS-128QAM transmission over 1-m wireless link, and it increases the maximal achievable information rate (AIR). Recently, the rotated-QAM is proposed as a power- and bandwidth-efficient diversity technique in the Rayleigh fading channel. It can improve the space gain of constellation and to expand the noise tolerance [7]. A rotated-QAM PS with fixed shaping rate scheme is analyzed through simulation in Rayleigh fading channel. The results show the superiority of rotated-QAM compare to the normal QAM scheme [8]. However, in W-band RoF system, it suffers from several impairments, such as the fiber chromatic dispersion and nonlinear effect of the signal modulation and detection. To jointly address these limitations, data-driven deep learning based algorithms are investigated in RoF systems and networks. It is a promising candidate for detecting the nonlinearity to achieve a better sensitivity [9].

In this paper, a rotated QAM-based PS-OFDM with ANN scheme is proposed and experimentally demonstrated for W-band RoF system. It can mitigate the frequency selective fading effect of the channel without extra matrix calculation. In addition, with the proposed scheme, the received optical power (ROP) sensitivity is enhanced compared to the traditional PS-OFDM.

2. Principle and Experimental Setup

For the rotated QAM-based PS-OFDM with ANN scheme, the digital signal processing is as follows: at the transmitter, firstly, after the pseudo-random bit sequence, PS 64-QAM is generated. It includes a distribution matcher (DM) and FEC coding to adjust the rate flexibly. The DM is used for generating different amplitude probabilities [4]. Here, the shaping rate R_{ps}=3.6 bits/symbols are used. The corresponding 3-dimension constellation is given in Fig.1 (a). Secondly, to further use the spatial gain of PS constellation, a rotated QAM-based PS (R-PS) scheme is proposed to improve the ROP sensitivity performance. It includes the angle rotation and I/Q interleave, as shown in Fig.1 (a). Based on the generated PS 64-QAM, a fixed angle coefficient is applied, and the angle is set as 45^{o}, which is proved as the optimal angle index [7]. Then, I/Q interleave is performed between two subcarriers, it means that Q part of the first subcarrier exchanges the value with I part of the last subcarrier [8]. In the way, the R-PS 64QAM is generated. Subsequently, at the receiver, after transmission over 50-km SSMF and 1-m free-space channel, the de-rotated of R-PS 64QAM is required. In the paper, to achieve the de-rotated process flexibly under different shaping rates, an ANN structure using one hidden layer with low training overhead is proposed. It is shown in Fig. 1(b). For the de-rotated process using ANN, it is performed as follows. Firstly, the quaduature (Q) and inphase (I) of several R-PS OFDM symbols are extracted as the input layer of the de-rotated ANN. Secondly, nonlinear activiation function is used in the hidden layer with five points to approach the ideal PS-QAM. Thirdly, the output layer using liner function is re-combined as the PS-OFDM symbols. The number of OFDM symbols and neurons in the training process is small, thus, the overhead and complexity of ANN is low. Finally, after the de-rotated of R-PS 64QAM with ANN, DM inversion and FEC decoding is used to recover data.

The experimental setup of the rotated QAM-based PS-OFDM with ANN is shown in Fig.1. In the transmitter DSP, bit stream is modulated as the 64QAM PS-OFDM with the shaping rate R_{ps}. Then, QAM rotation and I/Q interleave process are used to generate the R-PS symbol. After that, Hermitian symmetry, IFFT and CP insertion are applied to realize real-value OFDM. Subsequently, R-PS 64QAM OFDM signal are loaded into an AWG to convert to analog signal. At the transmitter, an external cavity laser (ECL1) with the frequency of 193.134THz is used, and the optical spectrum is shown in Fig. 1(c). The continuous lightwave from ECL1 is loaded into a Mach-Zehnder modulator (MZM), and it is modulated with the R-PS 64QAM OFDM signal. Then, a polarization controller (PC) is used. The other ECL (ECL2) with the frequency of 193.233THz is adopted, and the optical spectrum is shown in Fig. 1(d). Subsequently, it combines with the lightwave from ECL1 via an optical coupler (OC) to generate a lightwave spaced by 90GHz, and the optical spectrum is shown in Fig.1 (e). After 50km SSMF transmission, a 100-GHz PD is used for optical-to-electronic conversion. And 90-GHz W-band radio signal is generated and amplified before beamed through a horn antenna (HA). After 1-m wireless transmission, the received HA with the envelope detector (ED) to down-convert the signal. Then, the baseband signal is amplified by the EA and sampled by a digital storage oscilloscope (DSO). In the receiver DSP, it includes the symbol synchronization, CP removal, FFT, signal equalization. Then, the PS reversion process consists of DM and FEC decoding is applied for bit recovery. In the experiment, the IFFT/FFT size is 1024, the number of data subcarrier is 300. And CP length is 16, each frame consists of 216 OFDM symbols.

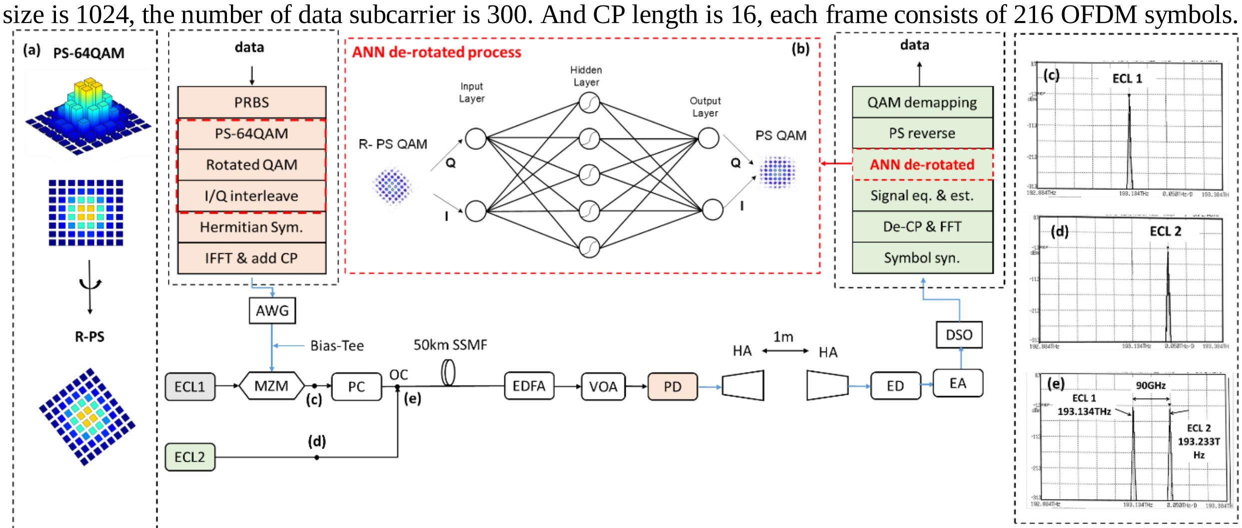

Fig. 1. Experimental setup with R-PS QAM DSP at the transmitter and receiver. Insets (a) the 3-D constellations of PS and R-PS 64QAM at the shaping rates R_{ps} , (b) the diagram of ANN de-rotated process, and optical spectrum from(c) ECL1, (d) ECL2, and (e) after OC process.

3. Experimental Results and Discussions

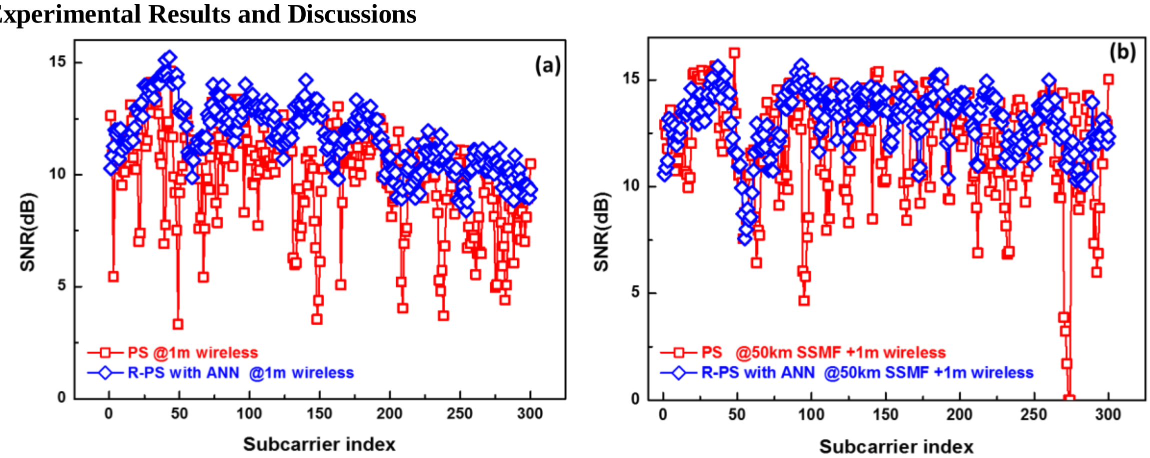

Fig. 2. The estimated SNR versus data subcarrier index for PS-OFDM and R-PS OFDM with ANN at the (a) 1-m wireless transmission and (b) 50km SSMF with 1-m wireless transmission.

Considering that the two cases such as 1-m wireless transmission and 50km SSMF with 1-m wireless transmission, the estimated SNRs of the PS-OFDM and R-PS OFDM with ANN scheme versus data subcarrier index are shown in Fig.2 (a-b), respectively. It is seen that, R-PS OFDM can realize a more stable SNR distribution than PS-OFDM in both cases. In the case of 1-m wireless transmission, it is affected by the frequency selective fading. It is obviously that the R-PS OFDM with ANN can improve the robustness to the frequency selective fading, compared with PS-OFDM scheme. In the case of 50km SSMF with 1-m wireless transmission, the high-frequency subcarriers are severely deteriorated due to the attenuation and chromatic dispersion of optical fiber. For R-PS OFDM with ANN, it can still maintain the SNR performance of high-frequency subcarriers, while the SNRs of PS-OFDM is decreased.

In addition, the GMI performance of PS-OFDM and R-PS OFDM with ANN scheme are compared in W-band RoF system. The GMI curves versus ROP for the PS-OFDM and R-PS OFDM with ANN are plotted as shown in Fig.3 (a-b). For 1-m wireless transmission, by using R-PS OFDM with ANN scheme, it can achieve 0.6dB ROP sensitivity improvement at the 3.6 bits per symbol. After 50-km SSMF transmission and 1-m wireless transmission, the overall performance is deteriorated. For the R-PS OFDM with ANN scheme, compared to the PS-OFDM, 1dB ROP sensitivity gain is obtained at the GMI of 3.6 bits per symbol. The corresponding constellations at the GMI of 3.6 bits/symbol is inserted in Fig. 3(a-b). It is clear that the constellation of R-PS OFDM with ANN is more centralized than that of PS-OFDM scheme, and the noise range of R-PS OFDM with ANN is smaller than that of PS-OFDM scheme. Therefore, the R-PS OFDM with ANN can effectively resist the dispersion and frequency selective fading.

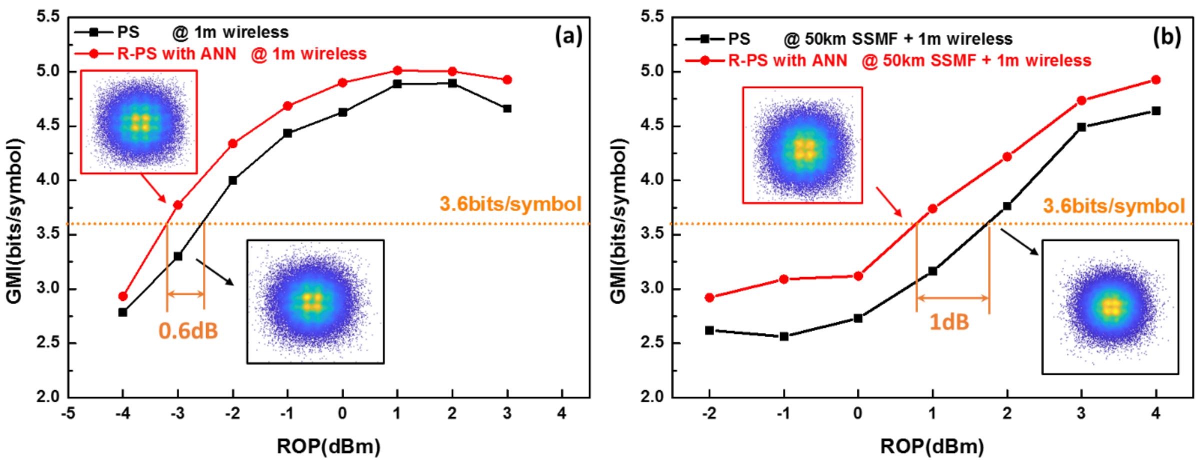

Fig. 3. Measured GMIs versus ROP of PS-OFDM and R-PS OFDM with ANN at the (a) 1-m wireless transmission and (b) 50km SSMF with 1-m wireless transmission, inserts constellations at the 3.6 bit/symbol.

4. Conclusions

In the paper, a rotated QAM-based PS (R-PS) OFDM with low-complexity ANN is proposed and experimentally demonstrated for W-band RoF system. R-PS OFDM with ANN scheme can use the space gain of constellation and expand the noise tolerance to enhance the performance. The experimental results show that, using the proposed R-PS OFDM with ANN scheme, it can achieve 0.6dB receiver sensitivity gain compared with PS-OFDM after 1-m wireless transmission. In addition, 1dB receiver sensitivity gain is obtained after 50km SSMF with 1-m wireless transmission.

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5. References

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