# Delivery of 103.2 Gb/s 4096QAM signal over 180m wireless distance at D-band Enabled by Truncated Probabilistic Shaping and MIMO Volterra Compensation

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**Abstract:** We experimentally demonstrated the delivery of 103.2 Gb/s 4096QAM signal over 180m wireless distance at D-band employing truncated probabilistic shaping and MIMO Volterra Compensation, with the value of NGMI exceeds the threshold of 0.83

## 1. Introduction

With the rapid development of applications such as virtual reality (VR), cloud computing, and the Internet of Things, broadband wireless communication systems have put forward higher requirements for communication rates. It is an inevitable trend for the carrier frequency of wireless mobile communication to develop to higher frequencies. The radio-over-fiber (ROF) system can integrate the advantages of optical fiber communication and wireless communication to achieve high-quality, long-distance signal transmission [1-4]. Compared with the limited bandwidth resources of traditional wireless transmission, D-band (110-170GHz) supports a larger transmission rate and bandwidth, can better support ROF systems, and has good development prospects in military and space communications [5].

It is well known that Orthogonal Frequency Division Multiplexing (OFDM) modulation technology has high spectral efficiency, good robustness to the dispersion in optical fiber transmission [6,7], and can effectively resist multipath effects in wireless mobile communication systems. Therefore, the photonics-aided OFDM ROF communication system is worthy of further study. Traditional low-order modulation formats such as QPSK can no longer meet the needs of high-speed wireless access networks. Increasing the modulation order is a relatively straightforward method that can effectively improve the spectrum efficiency [8]. In addition, a large number of documents have verified the superiority of the probabilistic shaping technology [9]: the signal after probabilistic shaping has better performance in the Gaussian white noise channel, and the value of mutual information is closer to the Shannon limit. However, the peripheral points in the QAM signal constellation are prone to non-linear distortions with the modulation order continues to increase, which makes subsequent equalization very difficult and leads to deterioration of system performance. Therefore, the advanced truncated probabilistic shaping (TPS) can be utilized to force the probability mass function (PMF) of the symbols in the outermost ring to zero [10], which will reduce the requirement for digital-analog-converter (DAC) resolution. Furthermore, I/Q MIMO Volterra equalization algorithm is used to compensate the nonlinear effect of system components on the high-order QAM signal.

In this paper, we have successfully demonstrated the delivery of 103.2 Gb/s 4096QAM signal over 180m wireless distance at D-band with NGMI over the threshold of 0.83, which is based on advanced digital signal processing (DSP) technologies including TPS technology, high-order modulation technology, and I/Q MIMO VNE. To the best of our knowledge, this is the first demonstration of up to 4096QAM D-band signal delivery over a 180m wireless distance with a net data rate over 100Gb/s.

## 2. Experiment Setup

The experimental setup diagram of the photonics-aided D-band RoF communication system is shown in Figure 1. We use two lasers, denoted as ECL1 and ECL2. ECL1 generates continuous-wavelength (CW) to carry signal, and ECL2 generates light waves as the optical local oscillator (LO). The wavelengths of ECL1 and ECL2 are 1560.428nm and 1561.427nm respectively, so the frequency interval between the two lasers is 123GHz. In order to obtain the maximum output power of the D-band signal, we set the optical power of CW and LO to be the same.

The DSP flow of the transmitting end is shown in Figure 1 (a). Among them, the PS-mQAM constellation probability distribution is shown in Figure 1(b), it can be seen that the probability of the outermost symbols is close to 0 with the modulation order increases, which will affect the convergence of the post- equalizer. Therefore, we utilize the TPS technique to force the PMF of the symbols in the outermost ring to zero and the remaining constellation points still follow Maxwell-Boltzmann distribution, as shown in Figure 1(c). At this time, the number of levels will be reduced, which can decrease the requirement for DAC resolution.

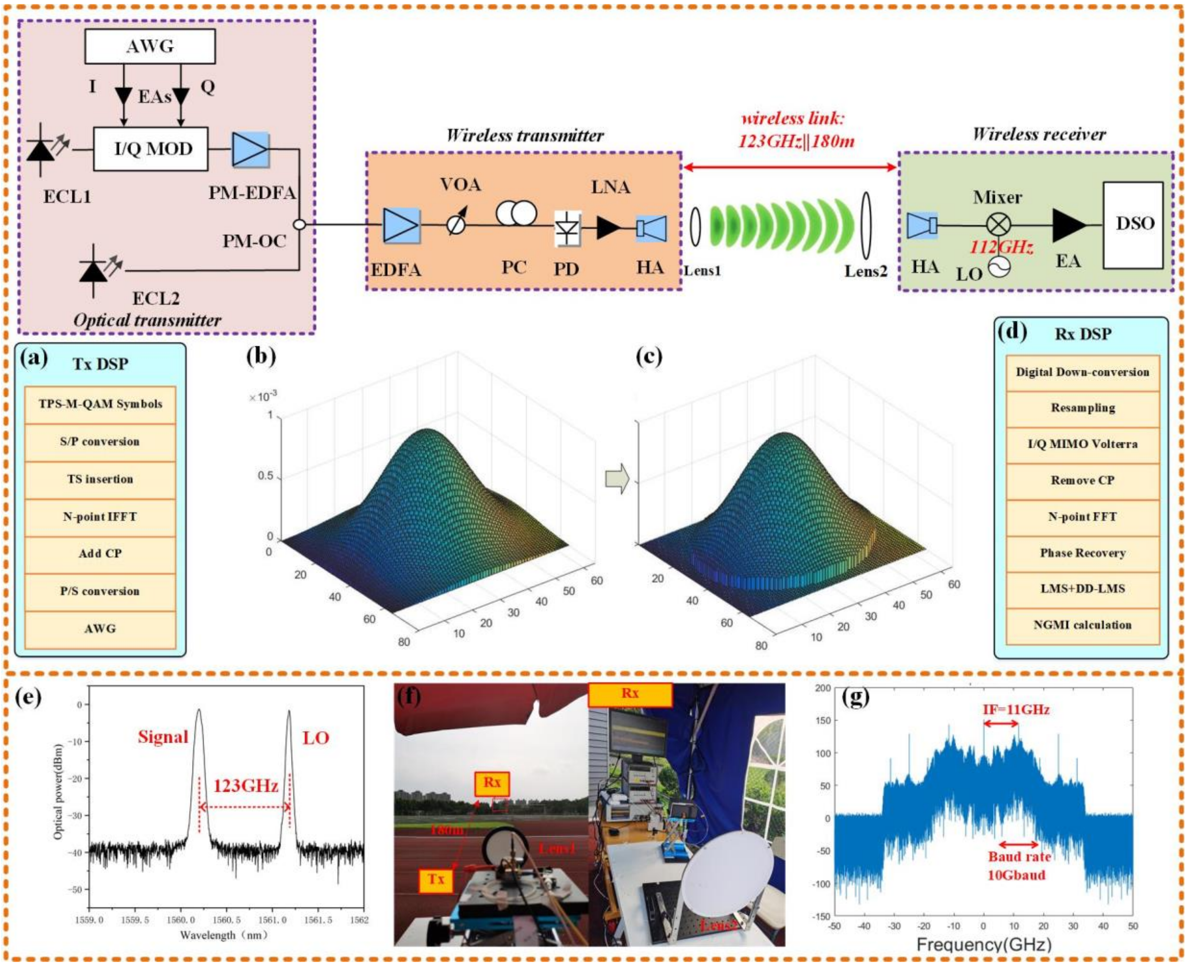


Fig. 1. The experimental setup diagram of the photonics-aided D-band RoF communication system; (a) block diagram of Tx DSP; (b) three-dimensional probability distribution histogram of PS-mQAM; (c) three-dimensional probability distribution histogram of TPS-mQAM; (d) block diagram of Rx DSP; (e) optical spectrums of the optical signal after PM-OC; (f) the experimental photos in the case of 180 meters wireless transmission; (g) electrical spectrums of the received IF signal

We use Tektronix AWG to convert baseband digital signal to electrical signal. The electrical signal output from the AWG is amplified by a pair of parallel EAs, and then the data is modulated by the I/Q modulator with a 3dB bandwidth of 32GHz and a half-wave voltage of 2.3V. Subsequently, the generated optical signal is amplified by a polarization-maintaining erbium-doped fiber amplifier (PM-EDFA), and then couples to the optical LO through a polarization-maintaining optical coupler (PM-OC). Figure 1(e) shows the spectrum of the optical signal after PM-OC. We use a variable optical attenuator (VOA) to adjust the optical power entering the PD after the optical signal is amplified by the EDFA, and add a polarization controller (PC) to control the polarization direction of the signal. Finally, the photodetector (PD) generates a D-band signal with a frequency of 123 GHz. The signal is first amplified by a low-noise amplifier (LNA) with a gain of 35dB, and then it is transmitted by a D-band horn antenna (HA1) with a gain of 25dBi. We use a pair of dielectric lenses to converge the signal and increase the transmission distance. The pair of lenses is composed of lens1 and lens2, and their insertion loss is less than 1dB. Among them, the diameter and the focal length of lens1 is 10cm and 20cm respectively. The diameter and the focal length of lens2 is 30cm and 50cm respectively. The lens1 and lens2 can provide 25dBi and 50dBi gain respectively.

Figure 1 (f) shows the experimental photos. After 180m wireless transmission, the D-band signal is converged by lens2 and then received by the other D-band horn antenna (HA2). At the wireless receiving end, the received signal is first mixed with the LO by the D-band mixer. The power of the LO is 13dBm and the frequency is 112GHz. Then, the signal is down-converted to an intermediate frequency (IF) signal with a frequency of 11GHz (123-112=11GHz). We use an EA with a gain of 30dB to enhance the IF signal, and finally use a digital storage oscilloscope (DSO) to capture it. The frequency spectrum of the IF signal with a baud rate of 10Gbaud is shown in Figure1(g), and the DSP process at the receiving end is shown in Figure1(d). We use the I/Q MIMO structure Volterra equalizer with 133 taps at the 1st-order and 289 taps at the 2nd-order to compensate the linear and nonlinear noise in the system transmission, use the Intra-symbol frequency-domain averaging (ISFA) for channel estimation, and finally cascade the LMS and DD-LMS with 27 taps algorithm structures as an equalizer to obtain a better recovered signal.

## 3. Results and Discussion

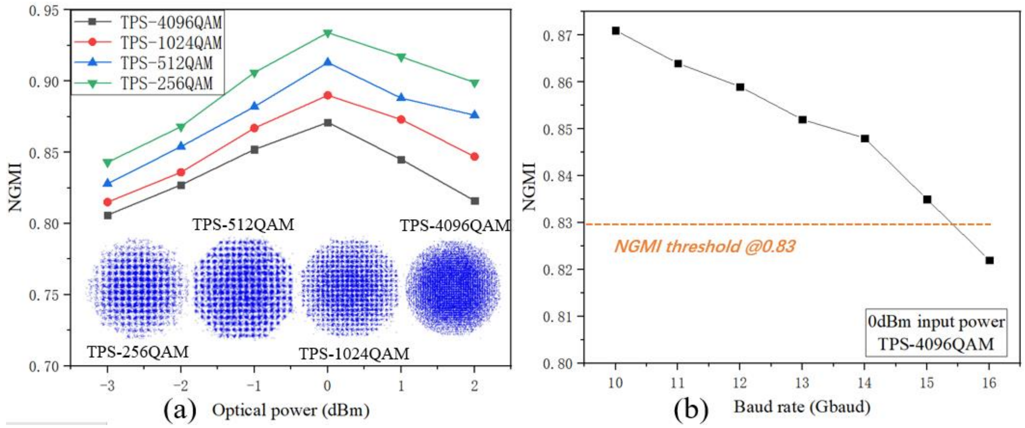


Fig. 2: (a) the relationship between the NGMI and the input optical power of the PD when the baud rate of the input signal is 10Gbaud; (b) the relationship between the NGMI and the baud rate of the input signal

we transmit 10Gbaud TPS-256QAM (7bit/symbol/Hz), TPS-512QAM (7.8bit/symbol/Hz), TPS-1024QAM (9bit/symbol/Hz), TPS-4096QAM (9.8bit/symbol/Hz) signal in the system respectively. As shown in Figure 2(a), we measure the relationship between the NGMI performance and the input power of the PD. We can see that the performance of NGMI deteriorates as the modulation order increases. When the input power of the PD increases from -3dBm to 0dBm, the NGMI performance is gradually optimized due to the improvement of SNR. When the input power continues to increase to 2dBm, the NGMI performance gradually deteriorates due to the saturation effect in the system. Therefore, the optimal input power of the PD is about 0dBm in this case, and the recovered signal constellation is shown in the inset in Figure2 (a).

In order to better test the performance of the system, we adjust the baud rate of the baseband TPS-4096QAM signal and measure the corresponding NGMI, as shown in Figure 2(b). When the signal baud rate increases, the signal bandwidth increases, so the channel attenuation increases, and the NGMI performance of the signal deteriorates. When the baud rate of TPS-4096QAM signal reaches 15Gbaud and the input optical power of the PD is about 0 dBm, we can achieve that the value of NGMI exceeds the threshold of 0.83. We know that the FEC threshold overhead corresponding to the 0.83 NGMI threshold is 25%. In addition, we use 990 subcarriers out of 1024 subcarriers to carry signal, add 64-point cyclic prefix (CP) to each OFDM symbol to resist the inter symbol interference (ISI), choose one of the 28 symbols as the training symbol for channel estimation in this experiment. We can calculate that the overhead of the OFDM signal is: $1-990/(1024+64)\times 27/28 \approx 12.26\%$. So we can calculate the maximum net rate as $15\times(1-12.26\%)\times 9.8\times 1/1.25=103.2$ Gb/s.

## 4. Conclusions

We have experimentally implemented a high-speed, long-distance photonics-aided D-band ROF system, in which, up to 103.2 Gb/s TPS-4096QAM signal transmission over 180m wireless distance is achieved employing TPS technology and MIMO Volterra compensation and so on. This achievement significantly enhances wireless distance performance and improves transmission capacity for radio mobile data communications, which will have a great use stage in the beyond 5G. *This work is supported by National Nature Science Foundation of China (NSFC) under grant No 61935005, 61922025, 61527801, 61675048, 61720106015, 61835002, and 61805043.*

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