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Impairments Approximations in Assembled mmWave and Radio Over Fiber Network

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Abstract: The fiber nonlinearity and phase noise (PN) are the focused impairments in the optical communication system, induced by high-capacity transmission and high laser input power. The channels include high-capacity transmissions that cannot be achieved at the end side without aliasing because of fiber nonlinearity and PN impairments. Thus, addressing of these distortions is the basic objective for the 5G mobile network. In this paper, the fiber nonlinearity and PN are investigated using the assembled methodology of millimeter-wave and radio over fiber (mmWave-RoF). The analytical model is designed in terms of outage probability for the proposed mmWave-RoF system. The performance of mmWave-RoF against fiber nonlinearity and PN is studied for input power, output power and length using peak to average power ratio (PAPR) and bit error rate (BER) measuring parameters. The simulation outcomes present that the impacts of fiber nonlinearity and PN can be balanced for a huge capacity mmWave-RoF model applying input power carefully.

1 Introduction

High capacity data transmission is the key goal of 5G mobile network, which is possible by combined structure of optical and wireless communication systems [1]. This mechanism has resolved

multi user and high definition (HD) data transmission issues over long distances. However, the enhancement of online services and video based data transmission have induced new impairments like fiber nonlinearity and phase noise (PN) [2]. These impairments have bounded the performance of existing communication setups. In struggle for new approaches, aiming to develop 5G mobile network flexibility, joint structure of millimeter wave and radio over fiber (mmWave-RoF) system is considered a promising solution [3,4]. Secondly, the cost effective and low complex framework like features have allocated the researches and various mechanisms are presented so far. For example in [5], the authors have proposed a solution for fiber dispersion and nonlinearities on quadrature amplitude modulation (QAM) signals of RoF system. The study in [6], compares different filters for optical microwave signals in RoF system and investigates the stimulated berrillion scattering. The power penalties by reason of nonlinear and dispersion losses were discussed in [7], applying split-step Fourier method. The performance limitations of RoF system by the influence of fiber nonlinearity are investigated in [8] based on analytical model. In [9], the authors have anlyzed a mixed free space optics (FSO) and RoF for enhancement system efficiency and addressing the impact of nonlinearities. Hadi. M.U [10] studied 64QAM-RoF system for 10 km range and nonlinearities are mitigated. The nonlinear impairments are suppressed in [11], for long range RoF system using 16, 32 and 64 QAM modulation schemes. Reference [12], explains teh low cost directly modulated laser for wavelength division multiplexing-RoF (WDM-RoF) system in order to enhance 5G mobile network performance. In [13], the authors have explored optical aided beam forming mechanism purposing to maintain RoF outcomes and balance the impacts of fiber nonlinearity optimally. RoF system is investigated in [14], using 128QAM and 40 Gbps signals, where the factors of nonlinearity are evaluated up to 70 km path covered using support vector machine (SVM) method. The paper [15], examines the feasibility of RoF system for 5G mobile network. The distortions induced by laser chirp are addressed successfully. The authors have suggested a RoF system for downlink and uplink modulations. The fiber nonlinearity impairments and PN are evaluated in this paper using the assembled methodology of mmWave-RoF. The model is investigated analytically using nonlinear parameters, PN and estimating parameters. The outage probability, peak to average power ratio (PAPR) and bit error rate (BER), fiber lengthand transmitted power are derived for huge capacity mmWave-RoF system. The impact of fiber nonlinearity and PN are quantified analytically for the first time in this paper.

In order to optimally balance the fiber nonlinearity and PN, the mmWave-RoF system is discussed in this paper. This research model includes the following major contributions.

1. Flexible 5G mobile network requires smooth communication setup, through which high capacity and HD based video are transformed accurately. Taking such point the mmWave-RoF is designed in terms of mathematical and outage probability investigations.

2. It is noted that long range, huge capacity transmission and intense laser input power generate fiber nonlinearity and PN, which are the key major factor of bounded RoF outcomes. These issues are minimized fruitfully using joint structure of mmWave and RoF including advance modulation frameworks.

3. The measuring parameters like bit error rate (BER), peak to average power ratio (PAPR) and optical signal to noise ratio (OSNR) are studied for evaluating system performance and impacts of fiber nonlinearity and PN.

4. The main elements like length of fiber, input and output powers, number of users are selected, aiming to detect the reason behind fiber nonlinearity and PN inductions.

5. The results are examined evolving 24 and 25 GHz RF range, 20 km fiber length, -38 to -18 dBm output power, and -8 to 0 dBm input power. That declares that the mmWave-RoF system

with advanced modulation schemes has ability to optimize the factors of fiber nonlinearity and PN and enhance 5G mobile network functions.

This paper is organized as follows, Section 2 describes the proposed setup of mmWave-RoF system, the analytical approach is discussed in Section 3, the results and discussion are examined in Section 4, in conclusion the proposed mmWave-RoF system is summarized in Section 5.

2 mmWave-RoF Presented Model

In this paper simple model of RoF is employed for fronthaul as depicted in Fig. 1. The mmWaves are received from source 's' point at RF access point, which are corrupted by affection 'M'. So, the signals are passed over band pass filter (BPF). After scaling the attained data at RF access node, the waves are modulated using advanced 16-64QAM modulation schemes. Average laser power is launched to mmWave signals, assuming mean = 0. Fixed gain 'G' is selected for modulating signal variance. This data are interrupted over long single mode fiber (SMF) and results in supplementary spare signals are created called nonlinear pulses. In addition, due to intense laser power the phase of transmitted waves is displaced as a result PN induced. These complex generated impairments gave key contributions against system performance. At central office the nonlinear and PN added optical pulses are investigated and optimally filtered optical BPF. The data are then converted in radio waves and overlooked by BPF for further purifications. The proposed model mentioned in Fig. 1 has plain structured as compared to existed RoF links. The united pattern of mmWave-RoF system has strong achievements over fiber nonlinearity and PN.
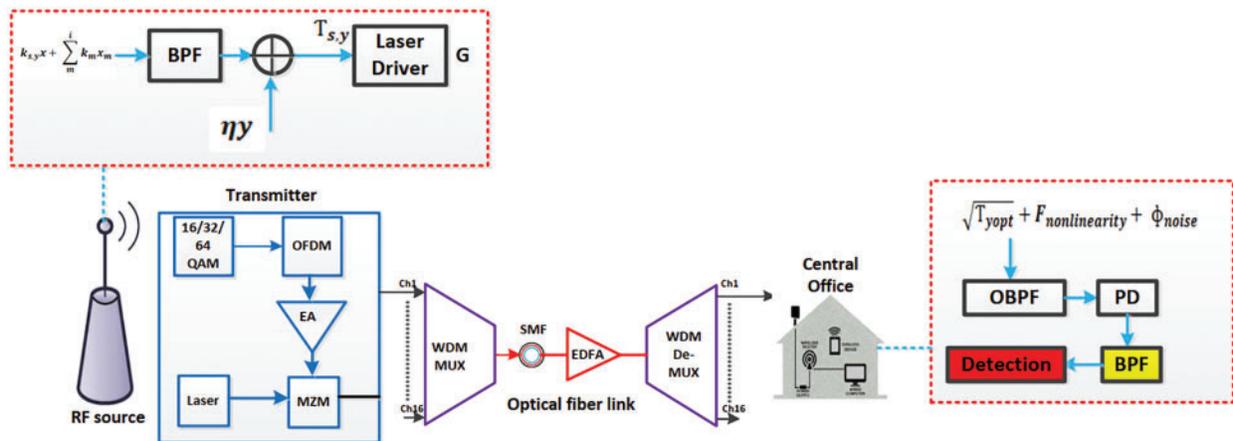

Figure 1: Presented structure of mmWave-RoF system

3 Analytical Investigations of mmWave-RoF Model

This section presents the theoretical analysis of mmWave-RoF suggested model. The attained signals from RF at transmitter end of the optical network are defines [16,17] as

$$\zeta_{s,y} = \kappa_{s,y}\chi + \sum_{m=1}^{i} \kappa_m \chi_m + \eta y \tag{1}$$

where fading coefficient is denoted by κ_m, $\kappa_{s,y}$ is RF channel, modulated symbol is defined by χ and ηy is the additive white Gaussian noise (AWGN) for mean = 0 and variance = $\sigma^2 y$. The RF signals

attained at the transmitter side of optical system, are assumed to be zero means with fixed gain G. Received electrical signals after loss compensation by amplifier are computed [17–20] as

$$\zeta_{s,d} = \psi(G\zeta_{s,d} + 2[\eta_{NL}\sqrt{\zeta p_i}] + \eta_d \tag{2}$$

where G is the gain, ηd is AWGN at variance $= \sigma^2 d$, responsivity of photodiode is declared by ψ and d is the destination. At d the signal to interference and noise ratio is written [21,22] as

$$\vartheta_r = \frac{\vartheta_1 \vartheta_2}{\vartheta_2 + \vartheta_2 \vartheta s + c} \tag{3}$$

where ϑ_1 and ϑs are the OSNR and interference to noise ratios, respectively. These ϑ_1 and ϑs are further calculated as

$$\vartheta_1 = \frac{\kappa_{s,y}|^2 p_i}{\sigma^2 s}| \tag{4}$$

$$\vartheta_s = \sum_m^i \frac{\kappa_i|^2 p_i}{\sigma^2 s}| \tag{5}$$

The parameter ϑ_2 used in Eq. (3) is the electrical SNR and measured [23–26] as

$$\vartheta_2 = \frac{\psi^2 p_o}{2\psi^2 p_o p_{NL} + \sigma^2 d} \tag{6}$$

$$c = v\sqrt{\vartheta_1' + \sum_{m=1}^i \vartheta_r' + 1} \tag{7}$$

ϑ_1' is expected value of OSNR and p_{NL} is the power consumption due fiber nonlinearity. Furthermore, the Rayleigh fading is assumed independent in this model, and ϑ_1 is dissolved exponentially.

$$f_{\vartheta_1}(\vartheta_1) = \frac{1}{\vartheta_1'} exp\left(\frac{-\vartheta_1}{\vartheta_1'}\right) \tag{8}$$

The dissolved ϑ_r provides the random variables of independent and identical exponential, which is the gamma distribution and written as

$$f_{\vartheta s}(\vartheta s) = \frac{\vartheta_s^{I-1}}{\vartheta_{si}' \epsilon(I)} exp\left(\frac{-\vartheta_s}{\vartheta_{si}'}\right) \tag{9}$$

where ϵ is used for gamma function. In order to estimate the mmWave-RoF outage probability, Eq. (10) is used in terms of threshold of communication performance 'ϑ_{th}'.

$$p_{out} = \int_0^\infty p_s[\vartheta_1 < \vartheta_{th}\frac{\vartheta_2 + \vartheta_2\vartheta_s + c}{\vartheta_2}]f_{\vartheta s}(\vartheta s)d\vartheta s \tag{10}$$

Substituting Eqs. (8) and (9), the Eq. (10) can be discussed as

$$p_{out} = 1 - \left(1 + \frac{\vartheta_{th}\vartheta_{si}'}{\vartheta_1'}\right)^{-I} \times exp\left(\frac{-\vartheta_{th}(\vartheta_2 + c)}{\vartheta_2\vartheta_1'}\right) \tag{11}$$

The estimating parameter BER for modulated binary data is given as

$$BER = \frac{1}{2} - \frac{\iota^\tau}{2}\left(\frac{\vartheta_1'}{\vartheta_{si}'}\right)^\tau \omega\left(\tau, \tau - I + 1; \frac{\iota\vartheta_1'}{\vartheta_{si}'} + \frac{\vartheta_2 + c}{\vartheta_{si}\vartheta_2}\right) \tag{12}$$

where ω is the hypergeometric function, different modulation schemes are denoted by ι and τ. For maximum ϑ_s conditions, the asymptotic forms of Eqs. (10) and (11) are used. These are presented as given below

$$p_{out}^a = 1 - \left(1 + \frac{\vartheta_{th}\vartheta'_{si}}{\vartheta'_1}\right)^{-I} \times exp\left(\frac{-\vartheta_{th}}{\vartheta'_1}\right) \tag{13}$$

$$BER^a = \frac{1}{2} - \frac{\iota^{\tau}}{2}\left(\frac{\vartheta'_1}{\vartheta'_{si}}\right)^{\tau} \omega\left(\tau, \tau - I + 1; \frac{\iota\vartheta'_1 + 1}{\vartheta'_{si}}\right) \tag{14}$$

The asymptotic 'a' Eqs. (13) and (14) are expressed by RF channel properties and do not depend on ϑ_2. The fiber nonlinearity and ϕ limit the power performance inside SMF. Thus, to optimize the impacts of fiber nonlinearity and ϕ the partial relation among p_o and p_{out} are kept zero. The analytical derivation of the proposed mmWave-RoF are investigated for realistic elements as depicted in Tab. 1.

Table 1: Detail of enlisted parameters applied for evaluating mmWave-RoF performance

| Name of used parameter	Detail of used parameter
Input power	−18 to 0 dBm
Data rate	100 to 112 Gbps
Noise figure of optical amplifier	4 dB
Fiber range	20 km
Number of users	80
Channel bandwidth	24 to 32 GHz
Number of guard bits	100

4 Results and Discussion

In this work the wireless communication connectivity is enhanced for 5G mobile networks, utilizing the mmWave-RoF system. The outage probability of proposed system is derived in aforementioned section. The simulation calculations are studied in this section, employing the derived analytical approach. Fig. 2 justifies the performance for simple RoF and proposed mmWave-RoF model. This explains that the mmWave-RoF outcomes are efficient than simple RoF link. At lower input power like −10 to −6 dBm the system gives maximum BER neat to threshold. Fig. 2 also presents the comparison among 24 and 25 GHz RF waves, which proves that the mmWave-RoF includes higher RF waves, adds nonlinear signals to the original waves. The proposed mmWave-RoF model results using length of fiber and BER estimating entities are discussed in Fig. 3. The correlations between simple RoF system in terms of −2 and −4 dBm are investigated. Normally, with maximum fiber range the optical system induces worst outcomes on the account of fiber nonlinearity and PN. However, Fig. 3 shows that the mmWave-RoF system has maintained its performance at long distance and gives BER below threshold. On the other side the simple RoF system with −4 dBm laser power, contains major nonlinear issues. Received power as a function of BER estimations are viewed in Fig. 4 for 10 and 5 km path covered. The results are evaluated for both balanced fiber nonlinearity and PN and included fiber nonlinearity and PN. It is noted from simulation study that more power is consumed by reason of fiber nonlinearity based mmWave-RoF model. At 10 km path span, −2 dBm power penalty is recorded with 10^{-4} BER,

which above the threshold. Therefore, the investigations of fiber nonlinearity and PN are important in practical system, which are installed for huge capacity and long range transmission. Suggested mmWave-RoF system is tested for number of users which is the key parameter for 5G flexible network. This discussion is disclosed in Fig. 5, including 262144 samples and 100 guard bits.
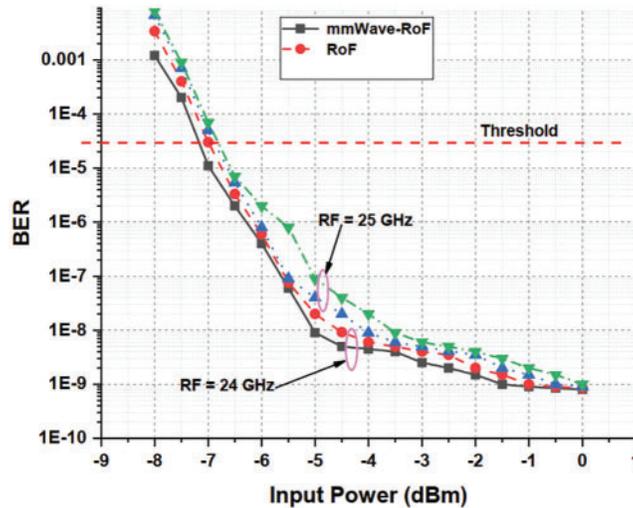
Figure 2: Experimental analysis of mmWave-RoF proposed model using input power and BER for 24 and 25 GHz RF waves
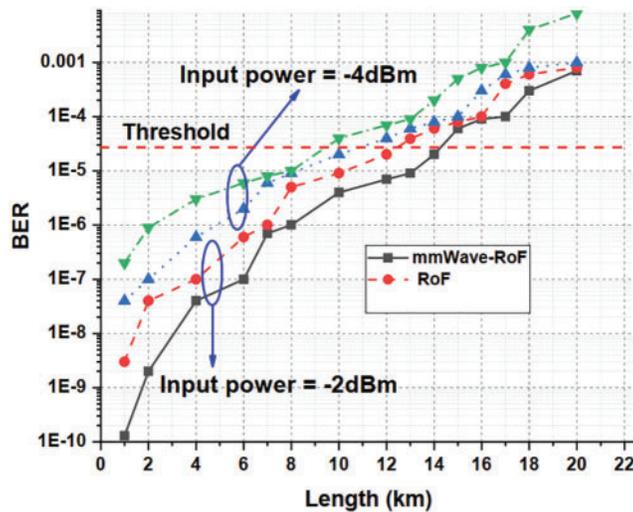

Figure 3: Comparison of existing RoF system and proposed mmWave-RoF system in terms of Length against BER
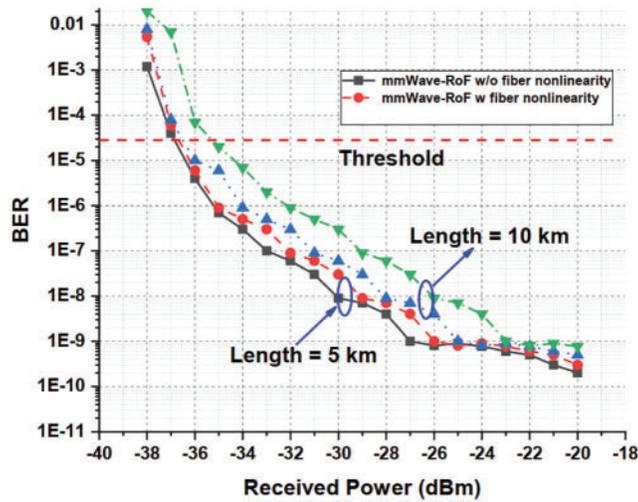
**Figure 4:** Experimental discussion of received power *vs.* BER for investigating fiber nonlinearity

In addition, Fig. 5 consists of fiber nonlinearity, PN and simple RoF model calculations, that express the badly corrupted data as a result of nonlinear impairments. These impairments become more prominent with maximum number of users. For example the mmWave-RoF system having users more than 50 gives limited BER. The same model with optimally balanced fiber nonlinearity and PN provides accurate information at the detector of the receiver side.
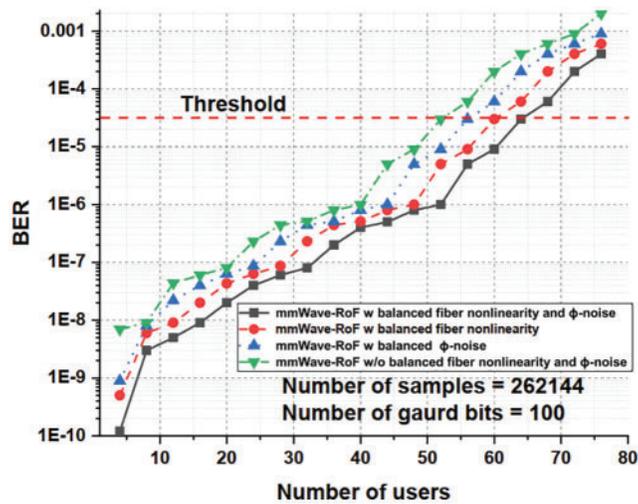

Figure 5: Number of users as a function of BER simulation estimations for ϕ-noise and fiber nonlinearity

The higher data rate speed such as 100 and 112 Gbps are applied at the proposed model and the estimations are judged among balanced fiber nonlinearities and PN mmWave-RoF system and unbalanced fiber nonlinearity and PN mmWave-RoF system. These measurements are included in Fig. 6 based on laser power and OSNR at 20 km transmission range. The analysis gives that the system with existing of fiber nonlinearity and PN signals provide worst results as mentioned in Fig. 6. Secondly, the OSNR of the system is improved after cleaning the pulses from the noises (fiber
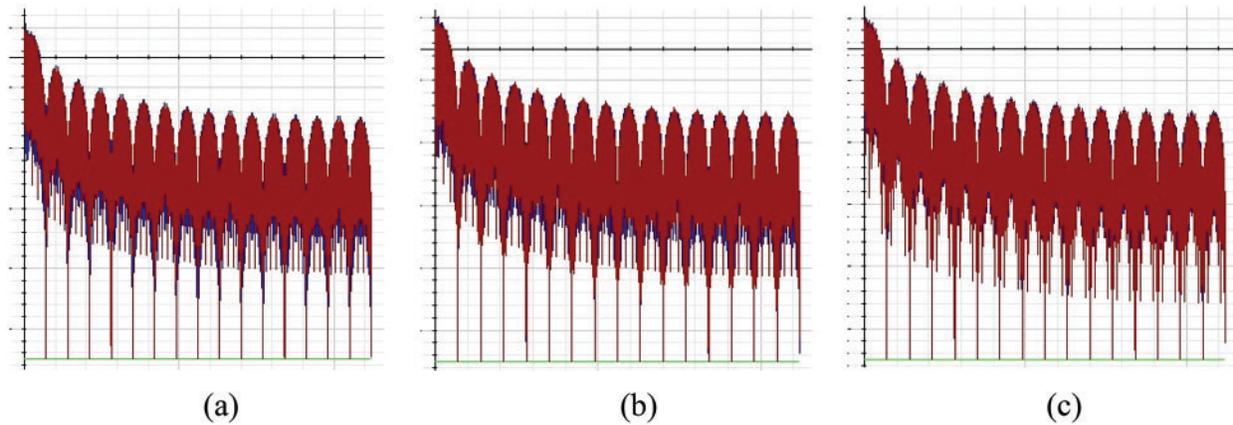
nonlinearity and PN). The back to back, nonlinear and PN consumed channels and cleans outputs waves, performance of the proposed mmWave-RoF system are evaluated using constellation and RF spectrum measurements. These calculations are provided in Figs. 7a and 7c at 112 Gbps data rate and 20 km covered path. The Figs. 7a–7c define that the proposed model has efficiently resolved the impairments of nonlinearity and PN for huge capacity transmission. Similarly, the comparison of Figs. 8a–8c depict that the high data rate signals are badly expanded due to fiber nonlinearity and PN. Thus, it shows a clear mechanism is always need to overlook the high order distortions for 5G networks as mentioned in Fig. 8c. In summary the Simulation study explains that the clear difference between balanced mmWave-RoF signals and fiber nonlinearity and PN added channels.
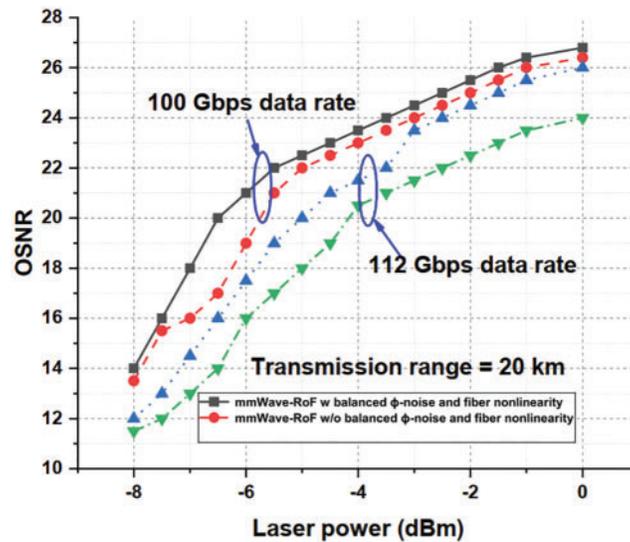
Figure 6: Laser power investigations against OSNR using 100 and 112 Gbps data rates
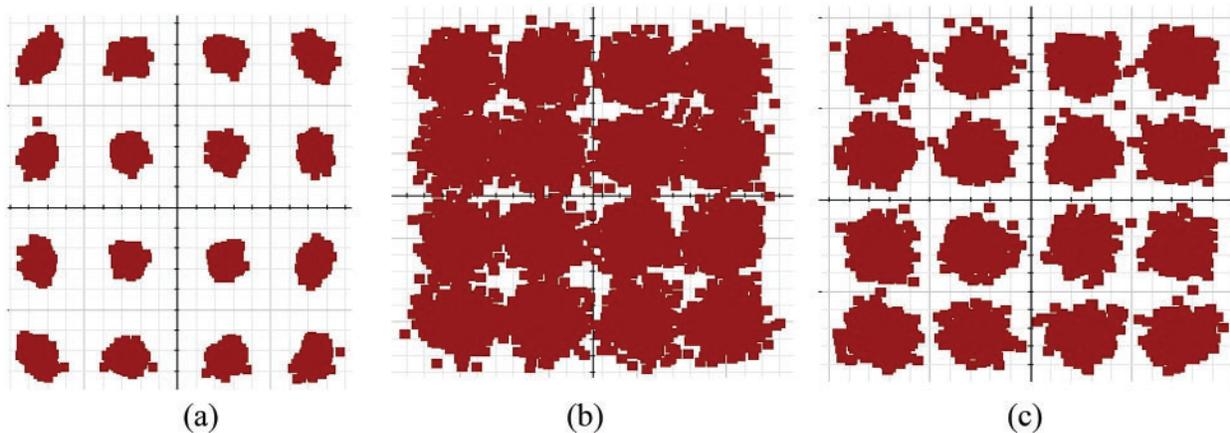
Figure 7: Constellation analysis of the proposed mmWave-RoF system; (a) back to back mmWave-RoF system performance, (b) fiber nonlinearity and PN included mmWave-RoF system performance, (c) optimally fiber nonlinearity and PN balanced mmWave-RoF system performance at 20 km transmission range and 112 Gbps data rate speed

Figure 8: Signals spectrum investigations; (a) Back to back signal spectrum performance, (b) The mmWave-RoF signals spectrum with fiber nonlinearity and PN, (c) Outcomes performance of mmWave-RoF system after optimally balanced the impact of fiber nonlinearity and PN at 20 km transmission range and 112 Gbps data rate speed

Tab. 2 explains the comparison of proposed architecture with existing models.

Table 2: Performance comparison of the presented mmWave-RoF system

Description	[2]	[26]	The presented mmWave-RoF system
Impairments addressed	Fiber nonlinearity	Fiber nonlinearity	Fiber nonlinearity, phase noise
Outage probability estimation	Yes	Yes	Yes
Length	10 km	12 km	20 km
Number of channels	1	16	64
Bandwidth capacity	32 GHz	32 GHz	32 GHz

5 Conclusion

In the existence of fiber nonlinearity and PN distortion mmWave-RoF system is discussed in this paper. The detail analytical model in terms of outage probability, performance and measuring elements are derived. The investigations show that for 5G networks need purified and flexibility based models, which can only be possible by managing the high order nonlinear impairments and PN. Looking to these required demands, simple and low-cost strategy is proposed in order to optimally balance the fiber nonlinearity and PN. The simulation estimations are analyzed using length of fiber, number of users, OSNR, BER and input/output powers. The results investigation concludes that the presented mmWave-RoF system efficiently develop the performance of transmitted channels at huge capacity and long-distance data transmissions. In future the mmWave-RoF exhibitions can be further improved, employing advance machine learning and artificial techniques.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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