Enhancing Fronthaul Network Connectivity by Utilizing a RoF-WDM Structure with MM Wave Transmission

Abdennour FELLAG CHEBRA[1†],
Ahmed Riad BORSALI[1], and **Mehdi ROUISSAT** [1,2], Non-members

ABSTRACT

The future 5G wireless system will provide communication systems with new advanced features to cover a large area with providing high bandwidth Millimeter Wave (MM Wave) processing speed, in which case transmission technologies become more important and require large amounts of data, a large number of channels and lower cost. This paper reports the design of MM Wave optical generation with 60 GHz based on RoF-WDM technique for long-distance optical fiber. The bloc scheme consists of 64 channels generated using Dual-Port Mach-Zehnder Modulator (DP-MZM) modulators for high data rate optical transmission. The performance was evaluated and analyzed in terms of various parameters such as optical fiber distance, input power and data rate, the simulation results are reported using Bit Error Rate (BER), Q-factor, Optical Signal-to-Noise Ratio (OSNR), and Eye Diagrams. The System efficiency provides an average BER of 4.0309e-10 with an optical fiber link of 120 km and 10 Gbps data rate per channel, it also provides 18 Gbps per channel for 100 km of Standard Single Mode Fiber (SSMF). In this work, the integration of different techniques is viewed as a unique perspective of radio over fiber systems towards a wireless communication network.

Keywords: RoF, WDM, MM wave, OSNR, DP-MZM

1. INTRODUCTION

In this decade, the demands of daily life have seen a heavy dependence on advanced means of communication, which has led to the development of highly efficient transmission technologies. Modern telecommunications networks operate using high broadband capacity to provide services to a growing number of users. In 5G systems the large bandwidth communication and the large number of antennas in a small area rapport the MM Wave technology for the wireless connection.

The MM Wave wireless network operates using radio signal transmission over optical fiber, with a wave band ranging between 30 and 300 GHz [1].In the case of covering urban areas, MM signaling is used in the 5G system over a broadband access system with advanced optical transmission based on radio technique over fiber. To face the high data speed needed in 5G transmission, communication systems implement high-performance techniques such as RoF and WDM with MM Waves frequency systems [2]. Furthermore, the Radio over Fiber (RoF) technique is a conventional solution for optical fiber communications systems and mobile networks. This method takes advantage of the high capacity of the optical system to provide next generation broadband [3]. The broadband RoF represents the Radio Frequency (RF) signal transmission over fiber link by using the optical frequency light carriers [4].

The RoF communications system is based on an optical architecture with three sections the Center Station (CS), Base Stations (BSs), and the optical distribution network [5]. At CS the advanced modulation techniques convert the data information to optical carriers by using optoelectrical components such as laser light optical modulators, the electrical coders...

The BS receives the RF signals transmitted from the CS via the Fronthaul optical link for each small cell. The Fronthaul link enables the connection between the CS and BSs. The main factor in the optical transmission is centered in the modulation format to enhance efficiency against the optical fiber nonlinearity; the performance margin is the performance range of an optical transmission system with a BER $\leq 10^{-9}$. At lower power levels, system performance becomes unacceptable and independent of modulation format [6]. Wavelength optical multiplexing technique is a practical solution in broadband mobile networks. The use of Wavelength Division Multiplexing (WDM) increases the capacity and efficiency of the system. By mixing different channel wavelengths, WDM transmits these optical signals over a single fiber.

This paper presents an advanced optical transmission system using WDM architecture with the RoF technique based on MM Wave frequency. The performance of the RoF-WDM system is achieved by using the external

Manuscript received on May 15, 2023; revised on July 24, 2023; accepted on January 9, 2024. This paper was recommended by Associate Editor Kampol Woradit.

[1]The authors are with STIC Laboratory, University Aboubekr Belkaid, Tlemcen, Algeria.

[2]The author is with University Center Nour Bachir, El-Bayadh, Algeria.

[†]Corresponding author: abdennour.fellag-chebra@univ-tlemcen.dz

Digital Object Identifier: 10.37936/ecti-eec.2024221.252943

modulator DP-MZM to modulate the RF signal and the information bits, and the simulations were performed using Optisystem software.

The paper is organized as follows: Section 2 presents an overview of RoF system model with MM signals transmission. Section 3 provides the proposed system architecture and the system's simulation setup. Section 4 presents the simulation results and discusses network performance, finally, Section 5 concludes the paper.

2. RELATED WORK

Numerous papers have focused on the RoF-WDM systems with MM Wave operation, attracting considerable interest from both academic and industrial circles worldwide. This has led to extensive research exploring various design aspects and applications of these systems. They are of utmost importance in meeting the data rate and bandwidth requirements for 5G communication. The authors in [7] implemented a 16-channel dense WDM system using Dispersion Compensation Fiber (DCF), fiber Bragg grating, and chirped fiber Bragg grating dispersion compensation in a 5G system with Non-Return-to Zero (NRZ) modulation formats. High-speed transmissions based on RoF are vastly proposed for future communication systems. Such systems are based on frequencies of 20, 40, 64, 75, 80, and 110 GHz [8–11], but 60 GHz is most commonly used for MM Wave transmission over optical fiber due to a low penalty of 06 dB and 1.1 dB respectively over a length of 50 km of optical fiber [12–14]. The combination of RoF and WDM can improve cellular communications at different wavelengths carrying different signals through a SMF which means a large capacity system, greater flexibility, and simple network design and cost reduction.

In [15], the authors proposed a 16-channel 160 Gbps data rate with a WDM-ROF system. DCF and FBG were implemented in the optical link, with 50 GHz and 100 GHz channel spacing. The Design uses MZM to modulate electrical signal from 2 to 32 GHz with input power change from 5 to -15 dBm. Some previous methods have been proposed for MM Wave optical generation including wavelength-multiplying channels based on external optical modulation using MZM and optical amplifiers such as Erbium Doped Fiber Amplifier (EDFA) and Silicon Optical Amplifier (SOA). In recent research, RoF has achieved effective performance in transmitting baseband signals to low losses, less distortion, and also provides a minimum error rate. It uses Return-to-Zero (RZ), NRZ, and Gaussian modulation formats [16].

RoF-WDM system implemented in [17] at 100 GHz carrier frequency to configure four channels, optical fiber length increased up to 70 km using EDF amplifier but with BER value of 2.42e-10. Using a RoF transmission developed in [18] of an 8-channel WDM signal with 110 GHz MM Wave through a range of 100 km at a data rate of 12 Gbps. From the literature review, different RoF system needs to be improved in terms of one or more characteristics such as the capacity of data transmitted in the system, optical distribution link, number of channels transmitted, and flexible architecture that CS and BSs cover a large area. However, the proposed systems do not provide the required data rate, so they do not exceed 160 Gbps and do not provide wide transmission over optical fiber. Some are more complex to transmit many radio frequencies.

3. SYSTEM DESCRIPTION

The system design consists of a RoF technique for strong transmission and an optical radio solution with increased capacity. In this section, we demonstrate the RF optical modulation technique used in the system and WDM communication network over a single optical access fiber. The system exploits MM Wave signals to provide the optical transmission requirements in a 5G system, where no active optical component is used in the transmission link.

Taking advantage of RoF and implementing MM radio signals, the proposed architecture consists of an electrical and optical possessing in CS and BSs with a distribution optical network. Fig. 1 shows the proposed schematic of the RoF-WDM optical transmission system. The transmitter outputs 64 optical channels at a high data rate, the optical frequency ranges from 191.1 THz to 196 THz with a channel spacing of 100 GHz. Fig. 2 presents the optical RF modulator for transmission, the optical photonic conversion technique provided with an external modulation by using two DP-MZM.

The first optical DP-MZM modulates the electrical data with the Continuous Wave (CW) optical wavelength. This modulation technique uses a double-sideband suppressed carrier transmission.

The data signal generated using a 10 Gbps data rate bit generator is encoded in the NRZ modulation format to produce a rectangular electrical signal and is injected into the DP-MZM. The resulting signal is modulated again by the DP-MZM optical modulator with a sinusoidal frequency. The main function of the DP-MZM in optical communication systems is modulation.

The DP-MZM structure consists of a configuration in which a LiNbO3 crystal is used in each electrode for light propagation. This propagation takes place through an input optical branch, which divides the incoming light into two arms. These two independent optical arms are then recombined by the output arm. By applying electrical voltages to the upper and lower electro-optical arms, we can control the degree of interference and the two-phase modulators on the output optical branch, enabling us to control the output intensity. Using the optical modulation, it is possible to generate multiple orders of MM Wave signals at the output that vary according to the electrical signals used. Depending on the spectrum structure of the optical signal produced, modulation types can be divided into different categories.

For the first method, the optical spectrum generates an optical carrier with a symmetrical double SideBand (DSB). This is a simple optical method for transmitting

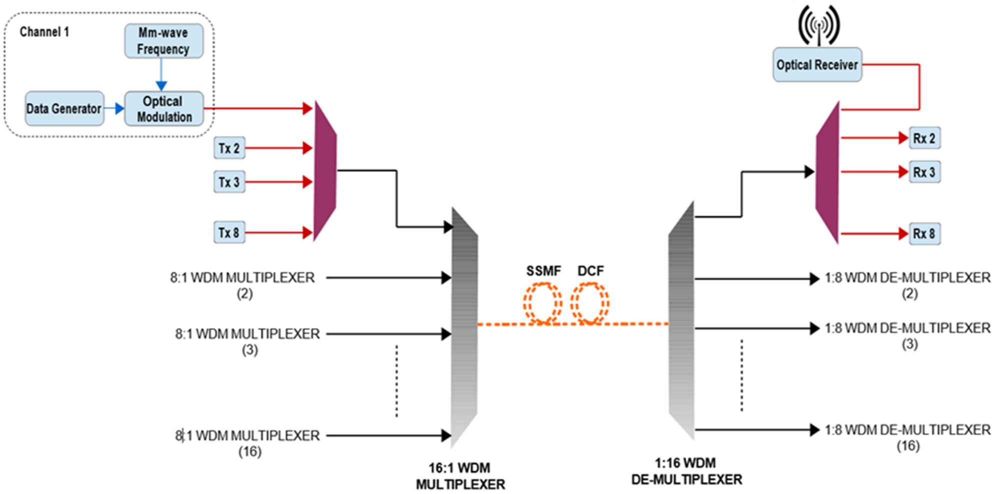

***Fig. 1**: Schematic diagram of the proposed system.*

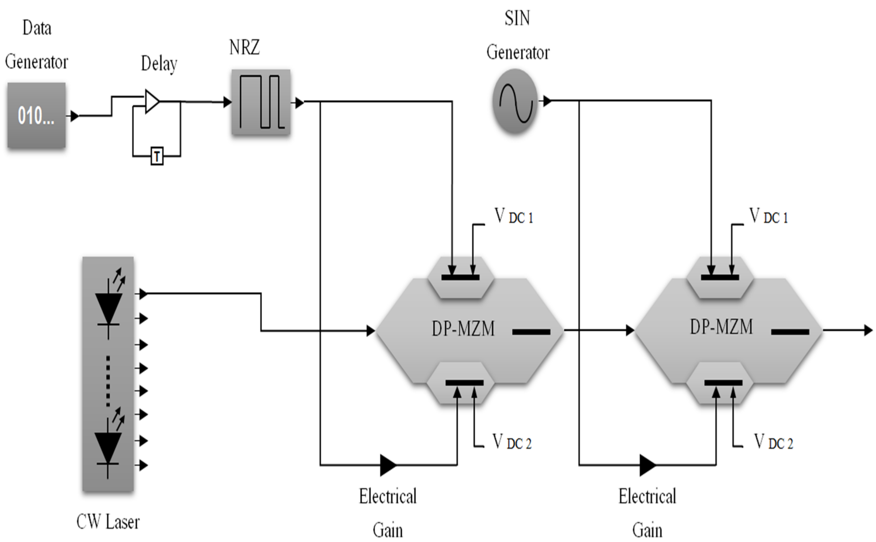

***Fig. 2**: Data optical modulator.*

information, and we can take one of the sidebands in the received signal. When the modulator's DC bias is adjusted to Vπ and apply an RF signal to the modulator arms with the same amplitude and angular frequency, but with opposite phases, this generates an Optical Carrier Suppression (OCS) signal and The RF frequency is the difference between the sidebands. The modulated signal will be transmitted through the two sidebands, which have large amplitude. The frequency of the modulated signal is determined by the difference between the frequencies of these sidebands. The optical signal emitted at the output of the 193.1 THz laser is given by Eq. (1).

$$E_{LD} = E_0 \exp(j\omega_c t) \tag{1}$$

where E_0 is the amplitude of the optical field and ω_c the angular frequency.

The light carrier wave is coupled with the data signal and passed through the first intensity modulator. This modulated output is then directed to the second modulator, which is activated by a Local Oscillator (LO) signal. The LO signal generates the two components, $V_{LO1}(t) = V_1 \cos(\omega t)$ and $V_2(t) = V_{LO} \cos(\omega t + \theta)$, driving the upper and lower arms of the modulator. In this context, V_{LO} represents the amplitude, ω corresponds to the angular frequency, and θ denotes the phase of the V_2(t) signal. The optical MM Wave optical signal is generated by modulating the RF signal with a Mach Zehnder dual-electrode modulator [19]. The output electric field from the DP-MZM can be expressed as follows Eq. (2) and the output-modulated MM Wave optical signal can be represented by Eq. (4).

$$E(t) = \beta E_{in}(t)[\gamma.\exp(j\pi\frac{V_2(t)}{V_\pi} + j\pi\frac{V_{b2}}{V_\pi})$$

$$+(1-\gamma).\exp(j\pi\frac{V_1(t)}{V_\pi} + j\pi\frac{V_{b1}}{V_\pi})] \tag{2}$$

$$\beta = \frac{1}{10^{(IL/20)}} \tag{3}$$

where $E_{in(t)}$ is the input signal, β represents the attenuation coefficient associated to the MZM be represented by Eq. (3), IL denotes the insertion loss parameter, γ represents the power splitting ratio, $V_1(t)$ and $V_2(t)$ are the input voltages for the upper and lower arms, V_{b1} and V_{b2} are the bias voltage settings and $V_ð$ is the half wave voltage.

$$E_{out}(t) = \beta^2 E_0 \exp(j\omega_c t)[\gamma . \exp(j\pi \frac{S(t)V_2(t) + V_{b2}}{V_\pi}) + (1-\gamma). \exp(j\pi \frac{S(t)V_1(t) + V_{b1}}{V_\pi})] \tag{4}$$

By setting the bias voltage to $V_ð$ the modulator generates an optical signal in which the carrier is suppressed. The upper and lower arms of the modulator are driven by LO signals of equal amplitude and angular frequency but with opposite phases. The output optical field of the double-sideband with suppressed carrier signal for each channel can be expressed as Eq. (5).

$$E_{out}(t) \approx \beta^2 E_0 m S(t) \exp(j\omega_c t)[\exp(j(\omega_c - \omega)t + \frac{\pi}{2}) + \exp(j(\omega_c + \omega)t + \frac{\pi}{2})] \tag{5}$$

$$m = \frac{\pi V_{LO}}{2V_\pi}$$

where $S(t)$ is the data signal and m is the modulation index.

The output signals of each channel are directed to the WDM multiplexers, which use 64 channels of 8-channel capacity with one multiplexer, 16 WDM signals are transmitted through the optical distribution network. The optical distribution system consists of a loop control of a network of SSMF and DCF, the optical signal is passed to the DCF, which provides equal and opposite dispersion to link dispersion.

The transmission simulation results vary according to the fiber length, for a distance up to 140 km. At the end of the optical network, the 64 optical channels at the output of the 1:16 demultiplexer are divided into 16 groups, each group contains eight channels. Then, the PIN photodiodes receive the optical signals from the WDM demultiplexer according to the corresponding wavelength by using the optical filter with the Gaussian frequency transfer function.

4. RESULTS AND DISCUSSION

The proposed system enables the transmission of RF channels over optical carriers with the WDM technology by utilizing multiple wavelengths. A SSMF is used to transmit signals from 64 optical MM Wave generators, with each channel carrying data at a speed of 10 Gbps. The system described in this paper uses a suppression method to eliminate the carrier and generate an MM Wave that carries data rate in the sidebands. The optical input and output of the fiber transmission spectrum are illustrated in Fig. 3.

Table 1*: Parameters used in the transmission.*

Parameters	Values
Data rate	10 Gbps to 20 Gbps
CW Laser power	0dBm to10 dBm
The frequency of the first channel	193.1 THz
Insertion loss (IL)	5 dB
Channel spacing	100 GHz
CW Linewidth	0.1 MHz
Phase shift	90°
LO frequency	30 GHz
LO amplitude	1 V
LO Phase	0°
Switching bias voltage	4V
Switching RF voltage	4V
SMF attenuation	0.2 dB/km
SMF Dispersion	16.75 ps/nm/km
SMF Dispersion Slope	0.075 ps/nm^2/km
Effective area	80 μm^2
DCF attenuation	0.005 dB/km
DCF Dispersion	83.75 ps/nm-km
Gaussian optical filter bandwidth	50 GHz
PIN responsivity	1 A/W
PIN dark current	10 nA

Fig. 4 displays the optical spectrum for a single channel, illustrating both the spectrum with the carrier suppressed and the spectrum without carrier suppression. Additionally, to improve the transmission performance of WDM channels, a DCF component is inserted after transmission through a 40 km with SSMF. Quantifying, analyzing and comparing the received data to the originally transmitted, allows for providing detailed system performance such as BER, Q-Factor, and eye height. The Q-Factor results are determined by the analyzer through the utilization of Eq. (6), while taking into consideration Gaussian noise characterized by standard deviations σ_1 and σ_0, the BER is calculated as Eq. (7). Design parameter specifications used in the simulation are presented in Table 1.

$$Q = \frac{|\mu_1 - \mu_0|}{\sigma_1 + \sigma_0} \tag{6}$$

where μ_1 and μ_0 are average values and standard deviations of the sampled values respectively.

$$P_e = \frac{1}{2} erfc(\frac{Q}{\sqrt{2}}) \tag{7}$$

Fig. 3 depicts the optical spectrum of the 64 WDM

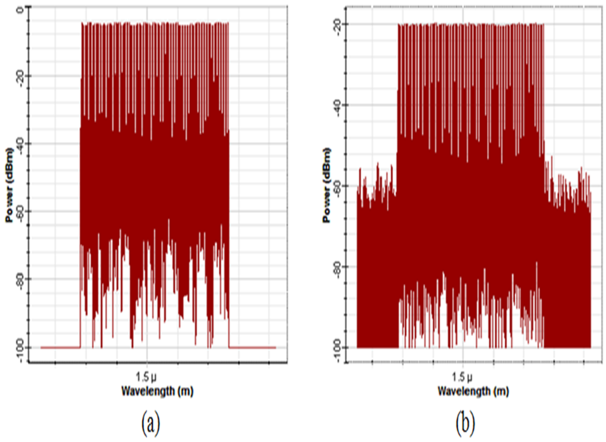

Fig. 3: *Optical transmission spectrum analyzer in (a) the optical link input, (b) the optical output link.*

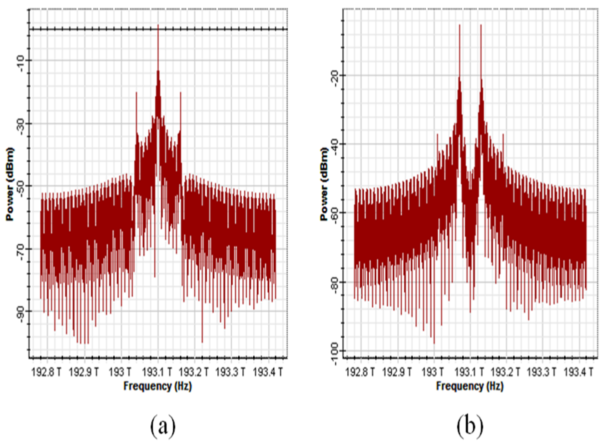

Fig. 4: *Optical spectrum analyzer for a single channel (a) shows the spectrum without carrier suppression, while (b) shows the spectrum with carrier suppression.*

channels before and after the optical channel. The performance of the WDM signals deteriorates due to attenuation and mixing of waves in the optical link, which leads to a decrease in the optical signal strength from -5 dBm to -20 dBm after transmission over the optical network.

Fig. 5 shows the Q-factor and the BER for the transmission rate of 10 Gbps, the SSMF performs transmissions over various distances, including 40 km, 60 km, 80 km, 100 km, 120 km, and 140 km. by using a CW optical power of 10 dBm. Through the obtained results in the transmission, it was observed that the lengthening of the optical fiber caused an increase in attenuation and chromatic dispersion in the signal, thus, the Q-factor of the system was reduced. The graph shows that the BER increases with the distance, where for an optical fiber length of 40 km the BER is 2,1627e-112, on the other hand, the BER shows a significant value of 9,964e-7 for a distance of 140 km. The transmission in the system indicates the high performance of a 64-channel WDM signal with a long optical distance of up to 120 km with a BER value of 4.221e-12, 1.8375e-11, 4.0309e-10, and 6.343e-11. Fig. 6(a) shows the results of the BER versus the optical injection power for the RoF-WDM optical network using 64 channels. Fig. 6(b) shows the BER values by changing the system capacity from 10 Gbps to 20 Gbps. From the plot of BER at different input powers with 100 km optical fiber length and 64 channel×10 Gbps design capacity, it can be seen that when the input signal strength exceeds 4 dBm the results value is greater than the BER limit. To find out the system performance against the data rate, the input bit rate is increased up to 20 Gbps per channel by considering that the length of the optical fiber was 100 km. From the performance obtained in Fig. 6(b), the designed link provides higher quality transmission since the obtained BER is much higher than 10^{-9} on a variable bit rate from 10 Gbps to 18 Gbps for all the 64-channels.

Fig. 7 shows the eye diagram for each transmission distance of a WDM–RoF network with a data rate of 10 Gbps and a carrier frequency of 60 GHz. These diagrams of the baseband signal demonstrate the distortion of the signal with increasing SSMF length. The results show that when higher transmission distances are used, the system performance deteriorates, especially for a distance of more than 140 km. This means that the noise corrupts the eye height of the received signal as the fiber length increases due to dispersion, amplitude distortion, and linear and non-linear effects. Table 2 characterizes the performance of the system in terms of OSNR concerning optical length.

Table 3 shows the OSNR with an increase in input power from 0 dBm to 10 dBm. For RF modulation data transmission, the signal can experience distortions, including stretching, due to various factors in the transmission path. These factors include the noise introduced by the transceivers, such as laser source and optical detectors, as well as other effects of the optical fiber link, such as power attenuation, dispersion, and nonlinearities. The OSNR results are used to determine the system's noise tolerance through the effect of transmitter distance and optical power of the lunched signals, to keep the BER above 10^{-9} the required OSNR is 32 dB or higher and the minimum received optical power is 4 dBm per 100 km SSMF.

The results shown in the figures above show the efficiency of the system as an optical fiber transmission based on the high capacity of the channels with optical MM Wave modulation. The WDM is used to increase the number of channels transmitted on a single link. Several performance improvements have been made and presented to achieve the best results, culminating in the transmission of 60 GHz per channel over a distance of 120 km with SSMF, so that the BER decreases after a distance of 130 km and becomes less than 10^{-9}. From the obtained results, the RoF signals of the system suffer various degradations in long optical transmissions due to the attenuation and fiber noise effects which appear in the OSNR and BER degradation. Furthermore, the quality

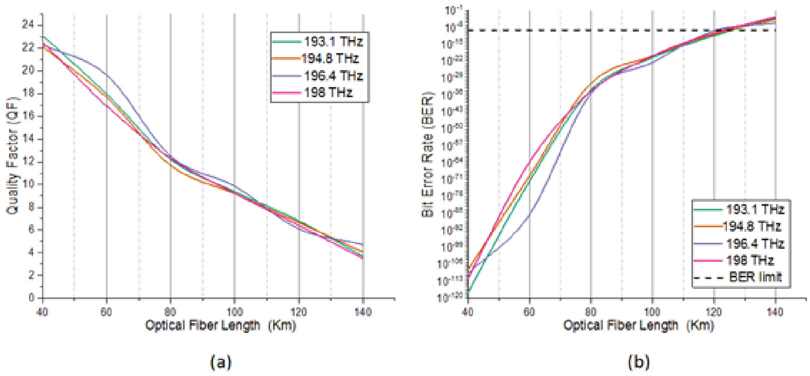

***Fig. 5**: The transmission performance versus distance of optical fiber. (a) The Q-factor performance, (b) BER performance.*

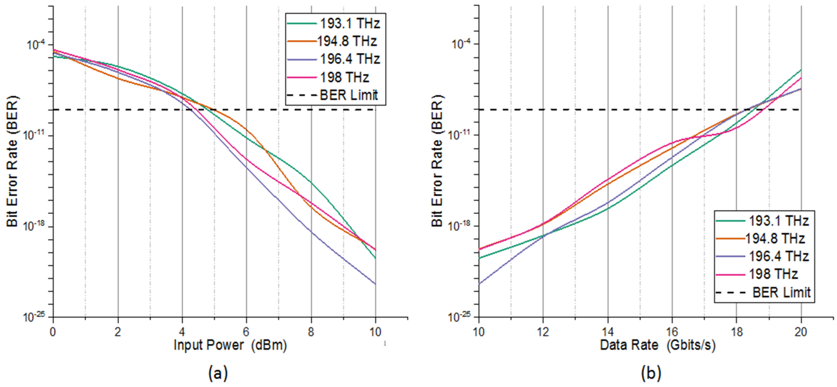

***Fig. 6**: The BER performance versus. (a) The Q-factor performance, (b) BER performance.*

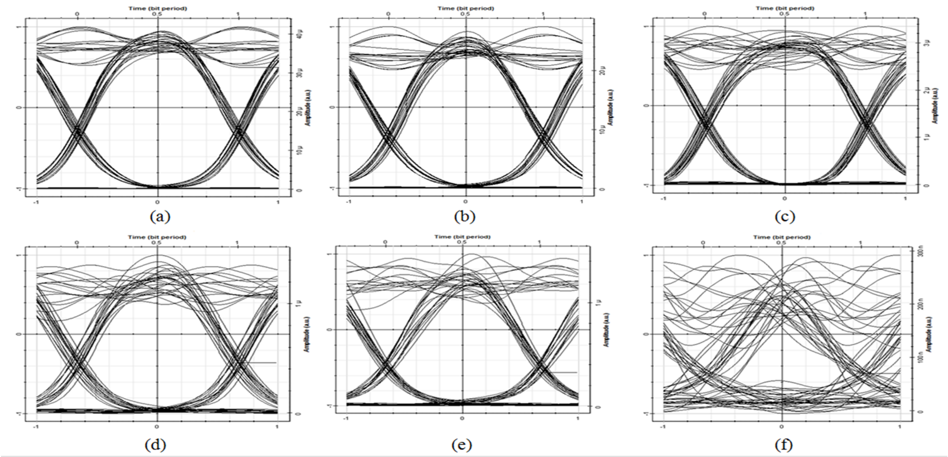

***Fig. 7**: Eye diagram of a WDM-RoF for different transmission distances. (a) 40 km, (b) 60 km, (c) 80 km, (d) 100 km, (e) 120 km, (f) 140 km.*

of the signals in terms of the lowest noise can only be possible with suitable parameters in the system which affects an acceptable BER. Besides; the system improves transmission quality while eliminating optical amplifiers and reducing the cost. To analyze the performance of the designed link by decreasing the input power from 10 dBm to 0 dBm, it has been verified that the received signals are corrupted when the weak transmission power is used, thus the SNR intensity decreases. For the case of increasing the data rate, it can be seen that the system provides high BER performance by changing the data rate from 10 Gbps to 18 Gbps for all 64 channels. It can be seen that all channels have the same performance when receiving the optical signals, the clear opening in the eye diagrams in Fig. 7(a) through Fig. 7(e) indicates successful transmission with the required received power and SNR ratio.

In Table 4, the performance of this proposed 64 WDM-RoF structure is compared with other recently reported WDM-RoF systems, such as described in references

Table 2*: Obtained OSNR values for 8 channels against fiber length.*

Wavelength (THz)	OSNR (dB)					
	40 km	60 km	80 km	100 km	120 km	140 km
193.1	53.8825	50.0603	41.2352	36.8773	33.0995	28.8541
193.8	54.2027	50.2159	41.0185	37.1974	32.8322	29.0148
194.6	54.0767	49.7234	41.0654	36.8337	32.8142	29.2078
195.5	54.0267	50.0784	41.0404	37.0784	33.0593	29.1976
200.2	54.0605	50.0158	41.0615	36.9744	32.9908	29.0421
200.8	54.2299	49.9827	41.2309	36.8604	33.1153	28.8024
202.5	53.9242	50.2013	40.9639	36.9976	32.7890	29.0388
205.1	54.92.42	49.2013	41.1024	37.0859	32.9086	28.8269

Table 3*: Obtained OSNR values for 8 channels against input power.*

Wavelength (THz)	OSNR (dB)					
	0 dBm	2 dBm	4 dBm	6 dBm	8 dBm	10 dBm
193.1	26.8382	29.0362	31.2181	32.7985	35.0566	36.8773
193.8	27.0130	29.2008	31.2075	32.9916	35.0130	37.1974
194.6	26.9019	28.7156	31.1832	33.2095	35.0557	37.0784
195.5	27.0113	29.0758	31.1983	33.0535	35.0244	36.9744
200.2	27.1682	29.0009	31.0258	33.0355	34.8628	36.8604
200.8	26.9831	29.0068	31.2139	33.0078	35.0741	36.9976
202.5	27.0055	29.2056	31.2226	33.0639	34.9638	36.8337
205.1	26.8723	29.0447	31.9116	32.9787	35.0501	37.0859

Table 4*: Comparative analysis of the proposed work.*

Ref No.	[20]	[17]	[18]	[21]	[22]	Proposed Work
Coding format used in Modulation	RZ/NRZ	NRZ	NRZ	NRZ	NRZ	NRZ
Optical modulation technique	OSSB-CS	ODSB	ODSB	ODSB	OSSB	DSB-OCS
Carrier Frequency (GHz)	-	100	110	-	15/25	60
Data Rate (Gbps)	10	10	14	8	2.5	10
Number of channels	8	4	8	32	12	64
channel spacing (GHz)	150	-	-	50–100	80	100
Input power (dBm)	15	0	0	-15 to 5	20	0
Distance(Km)	25	70	100	120	20	120
BER	1e-16	3.153e-009	6.49e-09	6.98e-48	1e-12	4.221e-12
Q-Factor	-	5.808	5.63	14.4589	-	6.655
OSNR (dB)	-	57.430	13.03	-	-	33.1153

[20], [17], [18], [21] and [22], in terms of transmission quality (Q-Factor, BER, and OSNR). Regarding the optical modulation technique, the proposed work uses ODSB-CS, which is different from other systems that use

ODSB, OSSB, or OSSB-CS. The choice of modulation technique affects the spectral efficiency and complexity of the system, thus reducing the efficiency of the system, particularly OSSB modulation techniques. The system's efficiency is compromised by the high data rate transmitted, which is a crucial performance metric that can be compared to other systems. Despite supporting an impressive 64 channels, other systems only offer a smaller range of channels, typically ranging from 4 to 32. The performance of systems utilizing the ODSB-CS modulation technique with a RoF-WDM structure and MM Wave transmission is efficiently achieved based on the readings of the Q-Factor and BER. In comparison to some of the referenced systems, the proposed work demonstrates superior performance. This indicates that our system can maintain high-quality transmission with minimal errors, allowing for communication over longer distances, up to 120 km.

The proposed work introduces a 64×10Gbps RoF-WDM architecture that combines 60 GHz transmission and DSB-OCS modulation. This innovative approach offers several advantages, including high data rates, long-distance coverage, and efficient use of the optical spectrum. The use of DSB-OCS modulation and the RoF-WDM structure contributes to enhanced system performance. DSB-OCS modulation guarantees excellent receiver sensitivity, preserving signal integrity and reducing noise interference. By eliminating the carrier signal, DSB-OCS modulation enables more efficient use of optical power. In addition, DSB-OCS modulation offers high spectral efficiency, enabling more information to be transmitted in the available bandwidth. By eliminating the carrier and using the two sidebands to carry the data, DSB-OCS modulation minimizes power penalties, which are degradations in signal quality [23]. The result is improved overall system performance.

In comparison to OSSB, this optical modulation technique offers several advantages. However, it does have some drawbacks. One of the main downsides is the increased complexity of the modulator system. SSB modulation requires additional components and circuitry to generate and suppress the undesired sideband, which adds complexity and cost to the overall system design. Additionally, SSB modulation can reduce the sensitivity of direct photodetection since only one sideband is transmitted [24], effectively reducing the received optical power by half when compared to other modulation schemes like double-sideband modulation. This reduction in received power can result in a lower signal-to-noise ratio at the photodetector.

Nonetheless, the significant improvement achieved by using the ODSB technique with carrier suppression and its low cost makes it a suitable choice for high data transmission over RoF-WDM with a large number of channels over SSMF. These characteristics make it well-suited for addressing the increasing demands of 5G and other advanced communication systems.

5. CONCLUSION

In this paper, we presented a Fronthaul system architecture based on RoF-WDM distribution technology for a 5G network. An optical RF modulation is invested for a 60 GHz MM Wave carrier. The purpose of the design is to achieve a large number of channels and a lower system cost. RoF-WDM transmission performance is evaluated by BER, Q-factor, OSNR, and Eye Diagrams. The simulation results show that the system performance provides successful transmission of 64 channels with 10 Gbps over 120 km SSMF.

The designed link shows high performance where the obtained BER for four channels is 9.2175e-11, 4.3717e-10, 4.0918e-10, and 3.89e-11 with a bit rate of 18 Gbps. Moreover, by performing the BER of the system with the input signal power exceeding 4dB and 100 Km of fiber length, the value of the result is greater than 10^{-9}; the proposed transmission requires a minimum OSNR of 32 dB and a channel spacing of 100 GHz to maintain an acceptable BER. Based on the results obtained, this work with MM Wave signal presents a significant improvement and effective solution for the RoF communication network that has the potential to be integrated into the 5G system.

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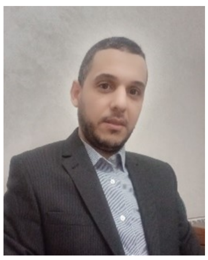
Abdennour FELLAG CHEBRA received a B.E. degree in Telecommunication and a M.E. degree in Networks and Telecommunications from the University Aboubekr Belkaid, Tlemcen, Algeria, in 2017 and 2019, respectively. He is currently a Ph.D. student in Wireless Communications and Networks at the same university. His research interests include Optics, Radio Communications, Wireless Networks, Radio over Fiber, and Networking.

Ahmed Riad BORSALI is Professor of Telecommunications at the University of Tlemcen, Algeria. He is graduated from the Ecole Nationale Polytechnique of Algiers in control, Postgraduate Diploma in Mobile and Satellite Communications from the University of Surrey, UK, and finally a PhD in Signal Processing from University Paris 12, France. Since 2007 he is a professor at the University of Tlemcen in optical communication and signal processing fields



Mehdi ROUISSAT rreceived his PhD degree in 2013 from the University of Tlemcen, Algeria, in the topic of Wireless optics. Currently, he is an associate professor at the University Center Nour Bachir of Elbayadh. He also worked as a Postdoctoral Research Fellow at Uninettuno University, Rome Italy, from September 2014 till July 2015. His research interests include Wireless and Optical networks, Security and QoS in IoT networks.