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REVIEW ON RADIO OVER FIBER SYSTEMS FOR CAPACITY ENHANCEMENT

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ABSTRACT

Radio-over-fiber (RoF) system is one of the latest plans for future wideband wireless communication systems like mobile communications, suburban and residential areas. These are good nominees to build the backbone of the next generation of wireless networks. Besides, the fundamental requirement for next-generation radio optical fiber and mobile communication is the need for more capacity and speed which has a huge scope, that is further required for a better system to attain demands such as Fiber to The Home (FTTH) and 5G. The combination of RoF with spectrally-efficient modulation techniques can accomplish increasing demand for high data rates for mobile users. Currently, analog fronthaul is promoted as an energy-efficient and bandwidth solution that can reach the necessity of the 5G vision for high data rates, low latency, and energy efficiency. Mainly, this paper presents a review that focuses on various techniques which several approaches have been listed to perceive the large-capacity data transmission and describe them including Wavelength Division Multiplexing (WDM), Subcarrier Multiplexing (SCM), Mode Division Multiplexing (MDM), Polarization Division Multiplexing (PDM), Generalized Frequency Division Multiplexing (GFDM), Parallel Intensity Modulation (PIM)/Phase Modulation (PM) transmitter, and Millimeter-wave (Mm wave) generation techniques. Also, a comparison between them has been done.

KEYWORDS: RoF, Multiplexing Techniques, PIM/ PM transmitter, Mm wave generation Techniques

(1) INTRODUCTION

With time, the requirement for rapid transmission velocity of data is building up. Presently, it is hard to visualize life without online high-resolution video streaming, video calls, biomedical sensors data aggregation, virtual reality experience, online gaming, Artificial Intelligence (AI) so on. All the above technologies need high transmission speed, minimum distraction possible, and high bandwidth. The Radio Over Fiber (RoF) system is a capability solution to maximize the capacity and mobility of access networks and can minimize the cost of access networks. Also, the recently developed mobile communication 5G depends on the RoF technology [1]. Primarily, the ever-rising desire for high data rates for applications as an example of video-conferencing, Television Internet Protocol (IP-TV), could be attended with the 5G mobile networks. The main goals of 5G networks are that traffic handling capacity 100 times more than 4G networks, low latency, large bandwidth, and gigabit serviceability for each user [2, 3]. Addressing different challenging requisites and providing new services are forecasted by the fifth-generation (5G) of wireless communications like Ultra-Reliable Low Latency (URLL) communication, massive Machine-Type Communication (mMTC), extremely huge throughput for enhanced mobile broadband (eMBB) applications, and long-range for the remote area access [4].

Ultra-high bandwidth capacity and multiple-Gbps data rate transmission are provided via

Next-generation Cloud Radio Access Networks (C-RANs) which is one of the essential performance guides for next mobile networks [5]. The integrated regulation of radio networks and fiber optics performs the abilities of the C-RANs, however, reliability, scalability, and cost need to be enhanced [5]. More ever, enhanced the Signal to Noise Ratio and least Bit Error Rate (BER) could be improved along with the requirement for more development reclarifying the RoF communication system with the appearance of technology. However, this needs the merging of large-capacity fiber communication and wideband wireless access. Therefore, these communication systems have been in a way further prevalent than other communication technologies [6]. Successfully, the variable bandwidth requirements have been handled by the developed optical networks for effective service transportation.

Fiber optical and appropriate choice of modulation techniques could simply attain the necessity for big bandwidth and high-speed which are always demanded in communication systems. Even though, modern modulation formats like Orthogonal Frequency Division Multiplexing (OFDM) integrated coherent detectors to maximize the spectral utilization efficiency to provide bigger bandwidth requirements however still the performance has been limited by inherent fiber nonlinearities. Taking advantage of Polarization Division Multiplexing (PDM) along with higher modulation formats can attain channel capacity four times more than single polarization mode transmission [7]. The evolvement of wavelength division multiplexing (WDM) technology was the first penetration to encourage fiber capacity. Further, higher-order modulation and polarization multiplexing is utilized to revive the capacity. However, next-generation WDM technology requires to be performed at 400 Gb/s or 1 Tb/s rate to achieve the global demand for network capacity. A lot of multiplexing techniques regarding complexity and cost are in research as an example of Space Division Multiplexing (SDM) with multiple modes and multiple core fibers. But several challenges are included in the implementation of SDM technology. Presently, to overwhelm the growing needs of network capacity, research is planning to maximize the transmission rate on single-mode fiber. The effective areas that more research has to be performed which are Forward Error Correction (FEC), fiber nonlinearity mitigation techniques and subcarrier multiplexing better performance of the network, and high spectral efficiency will be provided [8]. Moreover, merging the transportation of millimeter-wave (Mm wave) signals over the RoF system could be discerned as a promising nominee that would satisfy the need imposed via the 5G wireless system. With maximizing network capacity and data rates needs, transporting the radio signals over Fiber Optical Network (FON) in 5G was revealed to be a cost-efficient solution for delivering high-velocity radio signal transportation in the Mm wave band [9]. The remainder of the paper is arranged as below: in section two RoF techniques have been explained including the principle of operation, kinds, modulation technique, architecture, application, advantage, and limitation. In section three several techniques have been discussed for enhancing capacity. In section four comparison between several techniques has been shown with a table. Section five presents the conclusion of the paper.

(2) RADIO OVER FIBER (RoF) TECHNIQUES

Radio over Fiber (RoF) technology is the technique used for modulating optical signals by Radio Frequency (RF) signal over an optical link, which is discovered in 1990 for cordless telephone service. It comprises of Central Station (CS) which all frequency portion operation and RF signal processing like multiplexing, carrier modulation, and frequency up-conversion are performed CS is interconnected to several Base Stations (BS) by an optical fiber network and after that radiating into the antenna [9, 10]. The signal is generated at the CS. Also, in RoF technology, modulated RF signals are distributed from BS to Remote Antenna Unit (RAU) by using fiber optical links [11]. The BS converts Optical to Electrical signals by E/O and O/E converters. With the assistance of an antenna that is located at the BS unit, the signal transmission between the mobile units, base station and the user takes place as shown in Figure 1 [12].

Varying the output power from optical source can generate the modulated RF signal, that is transported over fiber optical link, which can be attained either by externally modulating laser source through intensity modulation such as Electro Absorption Modulator (EAM), Mach Zehnder Modulator (MZM) or phase modulator or by direct modulation**.** More ever, the direct modulation technique is also called Intensity Modulation (IM), and according to the RF signal, the amplitude of the laser beam is directly modulated. In the External modulation method, the phase of the optical carrier is modulated by utilizing a device such as MZM. It is favored due to that direct modulation is preferable for cheap transmitters, however, it is the source of an undemanding wavelength chirp which at high-speed causes unlimited chromatic dispersion. Because of many advantages like refractive index which is altered linearly with applied voltage and has stability at normal electronic operating temperatures. But the disadvantages of External modulation are high cost and complex system [13, 14].

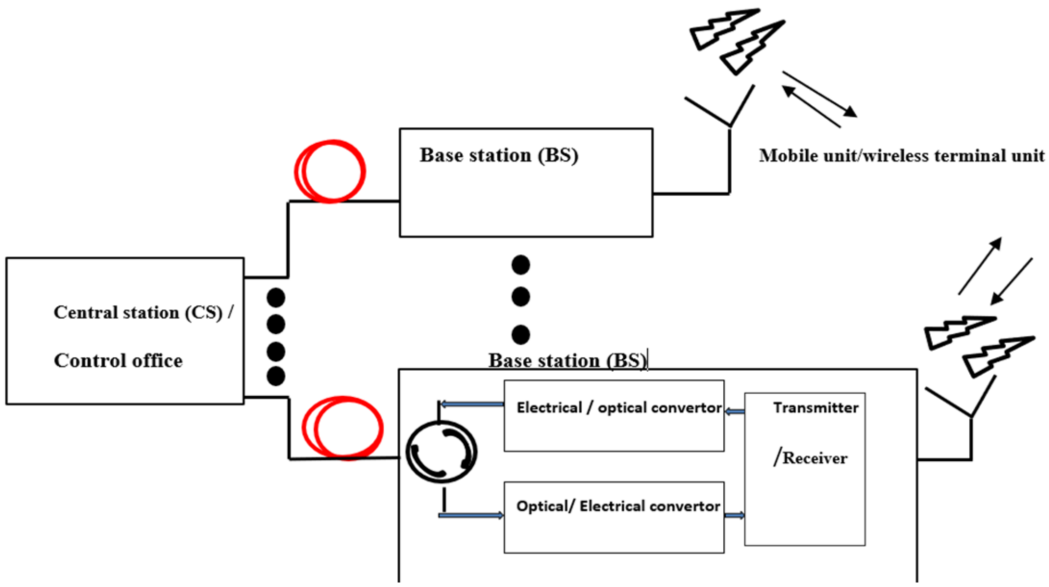

Fig (1): Radio over fiber block diagram [12]

2.1 Architecture of RoF

Rely on the frequency of transmitted signal, Intermediate Frequency Over Fiber (IFoF) and Radio the Frequency Over Fiber (RFoF) are the two classifications of radio over communication system. In RFoF, a high RF signal ($f_{rf} > 10Ghz$) is imposed on an optical carrier before transmitting by fiber optical connection. Also, the air-interface carrier (as the 28 GHz) is transmitted at the same time with signal through the fiber optical link. Then, the detected signal is directly transmitted confirmation air transportation, making the conformation of remote units uncomplicated. Therefore, at the base station, there is no necessity for frequency up/down conversion which consequences in simple and cost-effective application of circuitry. But, for exceeding the Mm wave band (e.g., > 28GHz), photonic devices need to be utilized such as Mach-Zander Modulators (MZM), Photodetectors (PDs) with a wide bandwidth that is very costly. On the other hand, in IFoF architecture, an Intermediate Frequency (IF) signal ($f_{if<10Ghz}$) is utilized for modulating the light signal and then conveying the modulated signal through a fiber optical link. So, signal processing is required at the BS before radiating through the air like frequency up conversion and amplification circuitry and the signal needs to be up converted to the Rf signal. Relatively, IFoF implementation could be done with low-speed photonic devices like PIN photodetector and Directly Modulated Laser (DML). Also, it permits to use of bandwidth-efficient transmission techniques depending on channel aggregation. Therefore, IFoF schemes will be more price and bandwidth-efficient for Mm wave service than RFoF [15, 16].

2.2 Advantages and Limitations of RoF Technology

The advantage and benefits of RoF distribution are low loss, large bandwidth, resistance from radio frequency interference, simple system, cost-efferent, low power consumption, maximizing channel capacity, multi-service, and multi-operation ability, uncomplicated installation and maintenance, improved cellular coverage, and dynamic resource allocation which making them appropriate for the requirement of wireless communication network [17]. Also, utilizing RoF has a lot of advantages to providing radio access as an example of cost-effective remote antenna units, the capability to install small, and ease of update for future potential investigation.

RoF appears to be a promising nominee, which will be broadly utilized for many communication network standards such as Digital Subcarrier Loop (DSL), Wireless-Fiber networks (WI-FI), worldwide interoperability for audio broadcast and digital video and microwave access (WiMAX) standards, that furnish high bandwidth and small power consumption whilst minimizing the cost of maintenance and deployment of wireless networks [18]. Simultaneously, the demand imposed by 5G wireless systems will be satisfied by RoF technology such as Multi-Input and Multi-Output (MIMO), and small cells schemes reported to be utilized in the 5G network could be profitably and simply implemented through this technology [19]. But, when this RF signal is propagated through a fiber optical channel, several abnormalities happened because of fiber characteristics such as dispersion, attenuation, and fiber nonlinearity which reduces the overall system performance. At the same time, the fiber optical deeds as a linear medium for small power level and nonlinear for large power level thereby affecting the optical fiber with non-linear influences which minimize the system performance.

One of the most objectionable phenomena of the present communication system is the nonlinearity effect, which causes intermodulation, harmonic, phase distortion, adjacent channel interference, and so on [9, 20]. The major fiber nonlinear influence in principal fiber optical communication systems is the scattering influence and Kerr nonlinearity that is generated via the modification of the refractive index due to signal intensity.

Attenuation tends to minimize the power of this signal when the optical signal distributing through fiber, and the maximum transmission distance of the optical signal could be determined. Whereat, broadening of pulse duration whilst traveling along the fiber is called dispersion. Also, Inter-Symbol Interference (ISI) is produced when the expansion of pulses gradually starts to overlap with each other. After some range, the pulses scarcely stay recognizable and if the signal transmits further, the pulses lose their information and specification [21]. Inelastic scattering is the cause of nonlinear effects in the optical fiber namely Stimulated Raman Scattering (SRS) and Brillouin scattering along with the Kerr effect. In the scattering effect, the optical medium absorbs a portion of the transmitted optical power [8]. The Modulation of silica Refractive index (RI) through variations in the signal's optical intensity which is called the Kerr effect causes nonlinearity. These consequences in various nonlinearities as per the form of the input field like Four-Wave Mixing (FWM) for multiple channels, Cross Phase Modulation (XPM) for a multi-channel, and Self Phase Modulation (SPM) for a single channel. In addition, signal impairments like noise and distortion are significant to RoF technology and analog communication too. Impairments limit the Dynamic range (DR) and Noise Figure (NF) of the RoF link. Based RoF system, Single-Mode Fiber (SMF), might limit the fiber link distance and might lead to enlarging RF carrier phase noise. Also, in Multi-Mode Fiber (MMF), these impairments limit distance, available link, and bandwidth [22]. Moreover, As the number of channels is maximized, the crosstalk due to inter-channel interference influences the performance of smaller channel spacings [5].

(3) CLASSIFICATION OF CAPACITY ENHANCEMENT TECHNIQUES

RoF system has a huge capability to attain low price, secure, and large capacity wireless communication for the coming interactive, wideband, and multiple media services. For the high data rate, modern communication is the 5G generation. It has a lot of advantages such as low jitter and delay, high reliability, spectrum availability, and higher capacity. To struggle with high data rate and capacity demand, optical fiber assists in the backhaul of the 5G network. For next-generation communication systems, there are several multiplexing techniques utilized for maximizing the capacity in multi-channel systems as Wavelength Division Multiplexing (WDM), Subcarrier Multiplexing (SCM), Orthogonal Frequency Division Multiplexing (OFDM), Polarization Division Multiplexing (PDM), and Mm wave generation which will be discussed in next subsection [23].

3.1 MULTIPLEXING TECHNIQUES

3.1.1 Wavelength Division Multiplexing (WDM)

The multiplexer combines the signals from various sources and pass into a fiber optical link, in the receiver unit, the aggregated channel is separated by a demultiplexer, and the signal is detected by a photodetector as shown in Figure 2. Adding channels on a new wavelength of light permits for multiplication in the capacity of a fiber optical which gives the ability for bidirectional communication over one strand of fiber. WDM takes benefits from a small amount of fiber bandwidth and fiber amplifier availability in the 1530-1560 nm wavelength windows [24]. The aggregation of WDM technology with RoF in remote areas will enhance the cellular communication system [25].

[26] designed an RoF system rely on Dense Wavelength Division Multiplexing (DWDM) and the proposed system consisted of 32 radio frequency (RF) transmitters to transport the signal over Single-Mode Fiber (SMF) optical link at different lengths. Also, it consisted of 32 base stations at the receiver. Loop control has been used to transmit the optically modulated signal through SMF for the selected distances of 60, 120, 180km.

The appearance of DWDM has elevated the significance of WDM and maximized its efficiency in capacity and bit rate which a large bandwidth would be utilized followed via various optical amplifiers without the requirement for optical and electrical converters which would be applied for longer distances making them more desirable. It used a huge number of channels with a low separation range between 12.5-200 GHz. Bit rate larger than 100 Gbps will be achieved [27].

[28] proposed a cost-effective DML-based WDM RoF conveyance network system to be utilized in the 5G system. Also, at the Remote Radio Head (RRH), flexible resource allocation experimentally has been provided under high and low traffic loads. The Error Vector Magnitudes (EVM) have been evaluated as a function of received and input optical power 4,16,64-Quadrture Amplitude Modulation (QAM) over the fiber optical link as shown in Figure 3. The main advantage of utilizing DML is that it is the simplest way to acquire intensity modulation of the optical beam by current driving the light source. They are utilized in applications with transmission lengths less than 100 km and low gigabit data transmission rates.

An analog 5G fronthaul optical network arranged with appearing CRAN has been proposed by **[29].** Also**,** the demanding requirements of hotspot areas are satisfied by generating an IFoF signal for each wavelength by exploiting WDM. To expedite reconfigurable wavelength switch working properly up to 4 wavelengths, Photonic Integrated Circuit (PIC)-depending on WDM optical transmitters is employed at the Baseband Unit (BBU) and Reconfigurable Optical Add-Drop Multiplexers (ROADM) cascading in an optical bus are utilized at the RRH as shown in Figure 4**.**

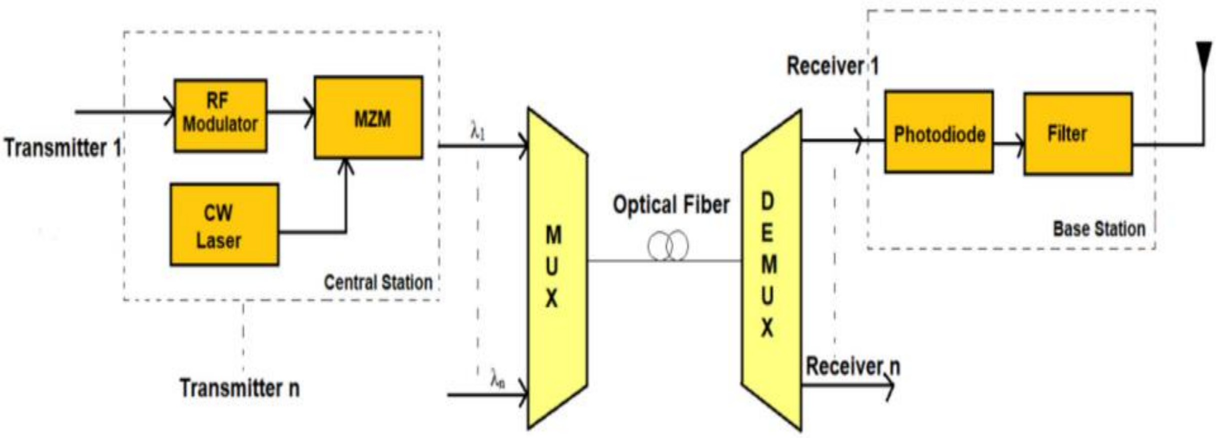

Fig. (2): Architecture of WDM-based RoF system [25]

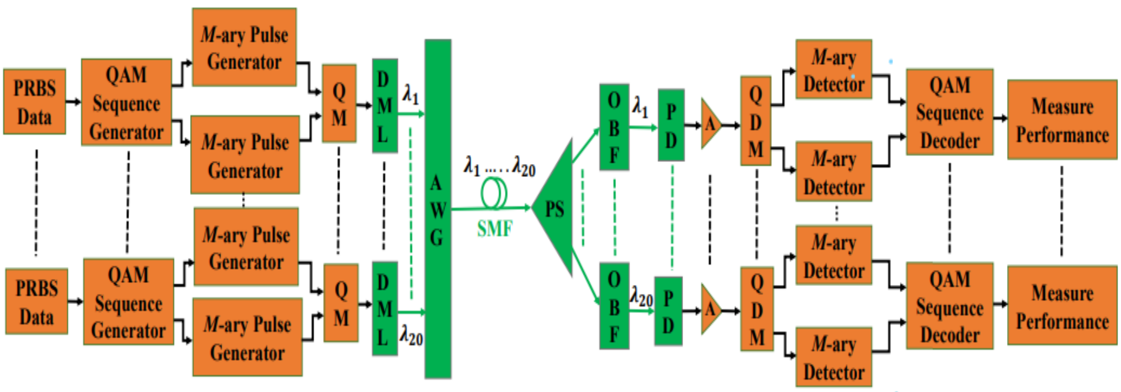

Fig. (3): Simulated diagram of DML based WDM-RoF fronthaul network for 20 channels [28]

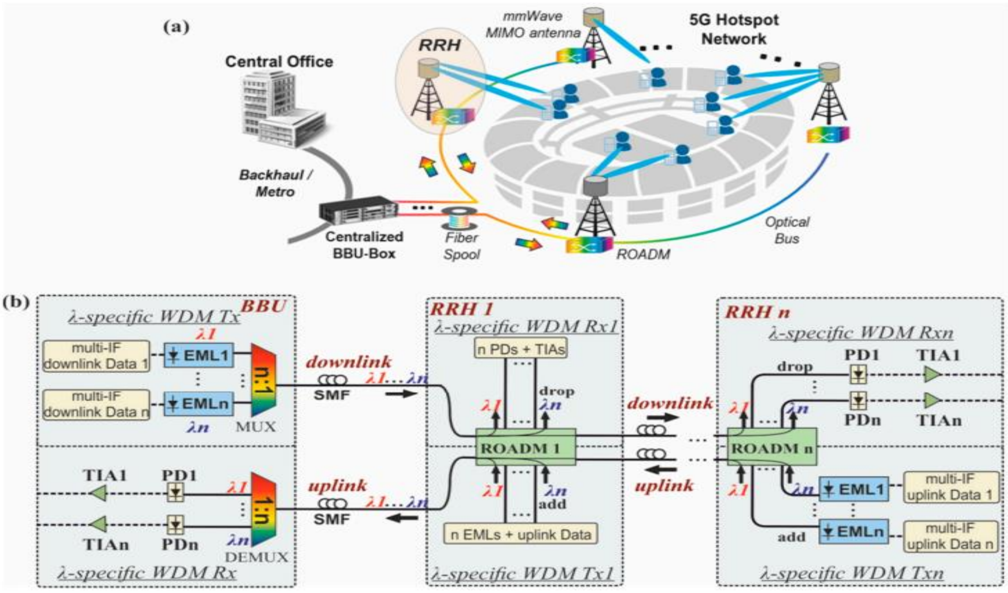

Fig. (4): (a) fronthaul architecture for hotspot areas. (b) diagram of BBU and RRH WDM wavelength-specific transceiver employed for the full-duplex communication system [29].

IFoF has appeared as a more prominent analog RoF technique that permits transmission of many aggregated IF bands signal, low cost, and bandwidth linear Externally Modulated Laser (EML)s are used to modulate the IF signal. These signals are transported by fiber in various IFs and before the wireless transportation, it is upconverted to Mmwave signal. In this way, the influence of fiber chromatic dispersion is importantly minimized, and utilize of low-cost and speed optical Tx Rxs make possible. An integrated photonic ROADM has been employed for every RRH to drop the WDM channels to the specific RRH or transfer it to the adjacent RRH of the bus, attaining in this way aggregation of the available optical downlink capacity to various areas of the stadium. Simplifying the block diagram function permits the system to be efficient by utilizing IFoF fiber optical links such as elimination of digitization and framing/de framing units or via utilizing small-signal bandwidth such as elimination of high-velocity electronic devices **[29]**.

[25] proposed a 16 channel WDM-based RoF system and the optimum power level from -15 to 5 dBm has been evaluated with the applications of Fiber Bragg Grating (FBG) and Dispersion Compensation Fiber (DCF) with channel spacing of 100 and 50 GHz. Optical signals of various lengths from whole CW lasers are modulated and then multiplexed by utilizing a WDM multiplexer for enhancing data transmission rate capacity. The combined signal is transported through SMF. In comparison to MMF, SMF has been utilized due to the capability of carrying an optical signal for a longer link distance at a higher data rate, despite that nonlinearities and high order dispersion affect the optical signal which limits the transmission length. A preamplifier is utilized before the receiver to improve demanded SNR and receiver sensitivity.

[30] proposed hybrid optical OFDM/WDM to furnish larger capacity and longer reach as compared to available PON system so that to meet the ever-increasing data rate and bandwidth demand of next-generation fiber optical access network. Also, two channels utilizing various modulations including QAM and PSK at 10 Gbps are used for downlink. OFDM signals are occupied various portions of the existing signal spectrum for signal transportations by using WDM. SNR degraded as the distance increased. In conclusion, better performance is achieved with QAM as compared to PSK modulation which controlling the phase during the transportation is hard with PSK. The SNR at 50km equals 23 dB whilst PSK at the same distance equal 17dB.

3.1.2 Subcarrier multiplexing (SCM)

The SCM technique can be performed in an optical system to maximize the efficiency of bandwidth employment. In this multiplexing, multiple RF signals in the frequency domain are multiplexed and transported via a single wavelength as shown in Figure 5. Also, the signals are severally modulated with various frequencies and an RF multiplexer is used to add them before converting them to an optical signal through an optical source and optical Modulator. The maximum subcarrier data rates and frequencies are limited due to SCM being more responsivities for the noise effect. Generally, conventional SCM seizes a broad modulation bandwidth due to its double sideband spectrum structure, so it is vulnerable to chromatic dispersion [31].

[14] designed RoF system-based WDM and SCM with various modulation schemes such as 4,16,64-QAM-OFDM schemes. The transmitter comprises the electrical and optical sides where RF signal is generated from the electrical side with SCM and the optical side is generated from the optical side with WDM. The transmitter part includes 8 channels of WDM and every optical channel comprise 4 RF Channels with a data transmission rate of 5 Gbps for every RF channel, and therefore 32 RF channel is generated. Also, at the receiver after photodetector, the electrical amplifier is used to amplify the received signal and compensate for the power which is lost because of power attenuation**.**

[32] investigated RoF-based SCM with modified Differential Phase Shift Keying (DPSK) and utilized an innovative kind of laser called Vertical-Cavity Surface Emitting Laser (VCSEL). A simulation model has been advanced to increase bit rate up to 20 Gbp/s and transmission length up to 200km with SMF. Different dispersion compensation techniques have been utilized namely DCF including pre, post, and symmetrical DCF, FBG, Optical Phase Conjunction (OPC) that allow to improve bit rate to 20 Gbps and compensate the dispersion effect through SMF. A Better result is achieved with FBG than the other technique when MZM is utilized with Avalanche Photodiode (APD) instead of Photo Intrinsic Diode (PIN). Also, signals are amplified by using an Erbium Doped Fiber Amplifier (EDFA). The DPSK removes the XPM and furnishes a crucial enhancement in the receiver sensitivity. Also, VCSELs have been widely utilized for optical communication and interconnections which have cost-effective packaging and testing. On the other side, 1.5 μm VCSELs are perfect nominees for fiber-optical communications due to the use of EDFAs which make possible long length broadcasting and application systems. Also, this laser has an advantage over conventional lasers such as lower manufacturing cost and threshold current, better wavelength stability, and large temperature operation up to 80°C.

[33] proposed an advanced model of RoF communication utilizing SCM/WDM techniques for four channels with not equal channel spacing and located EDFA 1km away from the transmitter. From the simulation result, it can be observed that the lowest noises and the bit error rate can be obtained when the EDFA is located 1km further away from the transmitter by utilizing Optical Single Sideband (OSSB) modulation at 193.1,193.2,193.35,193.6 THz frequencies. In OSSB modulation, the carrier and modulating signals are passed through two arms of dual-drive MZM (DD-MZM) at 90 degrees out of phase. After that, the modulated signal is aggregated via an adder/subtractor to produce single-sideband modulation as shown in Figure 6 **[34].** When an optical modulator is utilized to convert the RF signal to the optical domain in the frequency domain two side bands will be produced. This Double Sideband (DSB) signal is influenced by chromatic dispersion, wavelength, fiber distance, frequency of modulation, and fiber dispersion parameter, which makes a phase difference between the two bands to minimize system performance. This phenomenon could be overwhelmed by eliminating one side band, some techniques can be used such as dispersion compensating fibers, fiber Bragg grating, or utilizing advanced modulation to attain an OSSB signal [35].

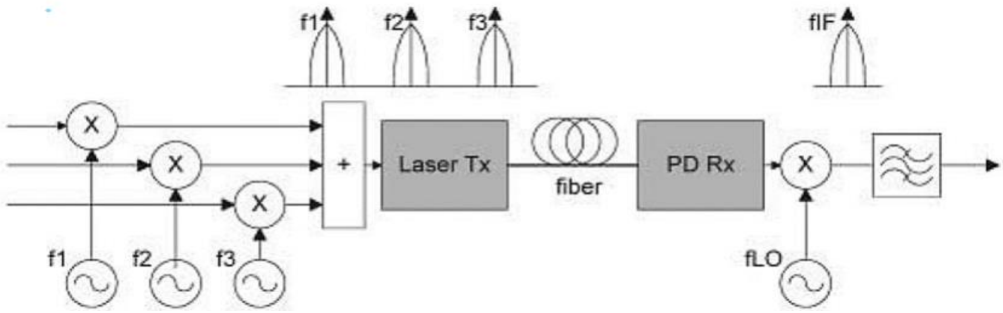

Fig. (5): Architecture of subcarrier multiplexing in ROF system after [31].

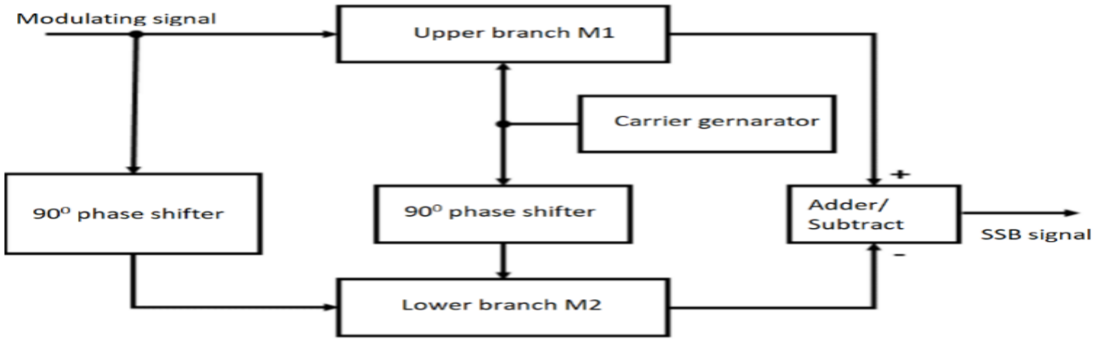

Fig. (6): block diagram of Optical Single Side Band Modulation (OSSB) [34].3.1.3 Polarization Division Multiplexing (PDM)

In PDM two orthogonal and linear States of Polarization (SOP) are aggregated and transported utilizing one wavelength. Simply, two orthogonal fiber polarization A and B could be utilized to multiplex the two optical beams on it. Also, due to continuous modification in polarization situations, their multiplexing is hard. SOP plays a pivotal character in quantum and classical mechanisms, in a different range of applications; but the spectral efficiency and system capacity is improved when SOP is utilized in high-capacity transmission techniques. Utilizing the PDM with higher modulation schemes such as TDM, WDM, SDM, and OFDM will quadrable the channel capacity **[7]** . But during transmission, it will cause Polarization Mode Dispersion (PMD) and therefore reduce the quality of service. In addition, spectrum utilization is limited when the signals transported with various polarization will reach at partly different times at the receiver which causes pulse widening, inter-symbol interference occurs with maximized BER and reduced Q-factor. This occurs because of enlargement in Differential Group Delay (DGD) with fiber distance. τ is the relation between DGD and PMD explicated in two equations:

$\vec{\tau} = \tau \cdot \hat{q}$ ……… (1)

$p_{\tau(x)} = \frac{8}{\pi^2 <\tau>} \left(\frac{2x}{<z>}\right)^2 exp\left(-\left(\frac{2x}{<z>}\right)^2 \frac{1}{\pi}\right)$ x $\geq$ 0 …. (2)

Equation (1) represents the stock formula of the PMD and equation (2) is the representation of DGD by Maxwellian probability. $\hat{q}$ denotes the lowest speed of principal SOP. The defective fluctuating and symmetry in fiber optical produces randomness in PMD making it hard to compensate and measure whilst dealing with higher data rates. In addition to PMD maximizing capacity also outcomes in XPM and cross talk in the transported RoF link [36].

[7] evaluated and proposed a fiber optical link based on PDM in joining with a Hybrid Optical Amplifier (HOA) for 16,64 QAM. Polarization Beam Controller (PBC), Polarization Controller (PC) splitter have been comprised to counter the PMD as well as with HOA, the fiber optical length varied from 30 to 160 km with a data transmission rate of 5Gbps. Without utilizing a hybrid configuration, the performance of the proposed link is compared with traditional OFC. Besides, for bit rate that is varied from 5 to 8 Gbps at 100km fiber distance, the hybrid amplifier configuration has been estimated. Two orthogonal polarizations are utilized by the designed communication link to carry various optical signals concurrently in the same fiber optical link. Driving signals for x and y polarizations are generated from the two QAM modulators, one with 4 and the other with 6 bits/symbol. To meet the fast progress demand in the designed layout, VCSEL has been utilized for data rate and efficiency improvement. A Polarization beam combiner is used to combine the two beams and then transferred through an optical fiber link. So that to compensate for mode dispersion influences, the PCs have been utilized with Azimuth 90 degrees and Ellipticity 0 degrees.

3.1.4 Mode Division multiplexing (MDM)

Multimode waveguide and its orthogonal spatial modes have been utilized by MDM to transport autonomous data channels and expedite effective huge bandwidth density data portion. Also, an extra dimension is provided by MDM for multiplexing. Cascade Asymmetric Directional Coupler (ADC) is used to realize MDM MUX/DEMUX. The ADC comprises of wider waveguide that higher-order mode is supported by this waveguide which is called the bus waveguide and a narrow waveguide supporting the TE_0 mode which is called the access waveguide. On the condition that phase matching is attained in the disappearing coupling area, mode coupling will occur when the access waveguide is nearby to the bus waveguide, as exhibited in Figure 7. The wider waveguide has various parts and optimized breadths; the phase-matching condition should be satisfied by every width so that to own mode multiplexing and de-multiplexing. Therefore, the fundamental mode (TE_0) traveling in the narrow waveguide could be coupled to the bus waveguide like higher-order modes or vice versa [37].

[23] Experimentally demonstrated silicon photonics (SiPh)-depending on RRH that 96 channels have been supported for the application of RoF MIMO. Modulation of every RF signal has been done with OFDM at 50 Gbit/s. 24 RoF channels of WDM and 4 x 4 MDM are employed to attain a total capacity of 4.781 Tbps. Experimental results present those 24 channels successfully could be mode multiplexed and demultiplexed in the SiPh RRH from 1525 nm to 1565 nm, and the 7% Forward Error Correction (FEC) threshold could be satisfied by every OFDM ROF signal. Every RoF signal comprises two optical tones with a channel spacing of 0.48 nm which represents 60 GHz. Distributed Feedback Laser (DFBs) is used to generate two optical tones. One of these optical signals is encoded with a 50 GS/s OFDM signal by MZM. Where an Arbitrary Waveform Generator (AWG) is utilized to produce OFDM signal, whilst other tone is the CW laser. Depending on the received OFDM subcarrier, the Signal to Noise Ratio (SNR) was operated to maximize bit, power loading, and spectral efficiency. Then, the OFDM optical signals and CW signals were aggregated via a 3-dB coupler to generate an RoF signal. After that, various WDM signals could be multiplexed by a WDM MUX and an on-chip grating coupler is used to launch the multiplexing signal to the MDM. The insertion loss of the integrated SiPh-RRH has been compensated by an EDFA. The Mm-wave signal is generated from the coherent beating between two optical tones when launched into Photodetector (PD) as shown in Figure 8.

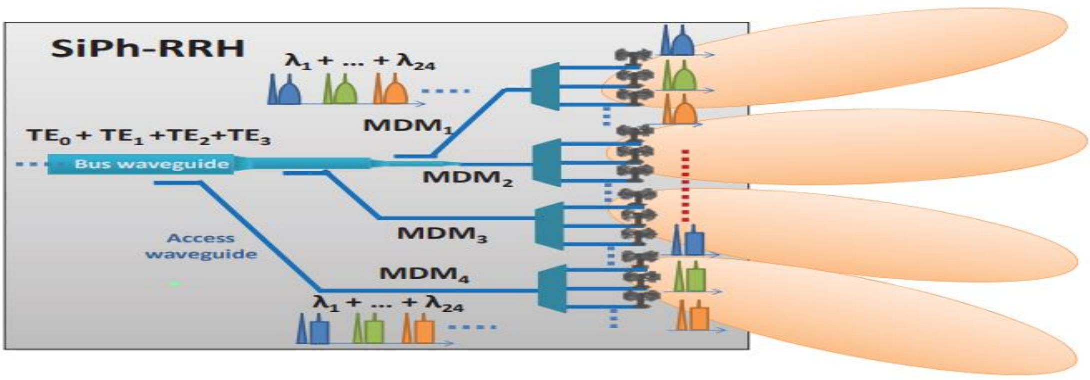

Fig. (7): suggested Architecture of SiPh-RRH based 4x4 MDM that supports 96 channels of WDM for MIMO [25].

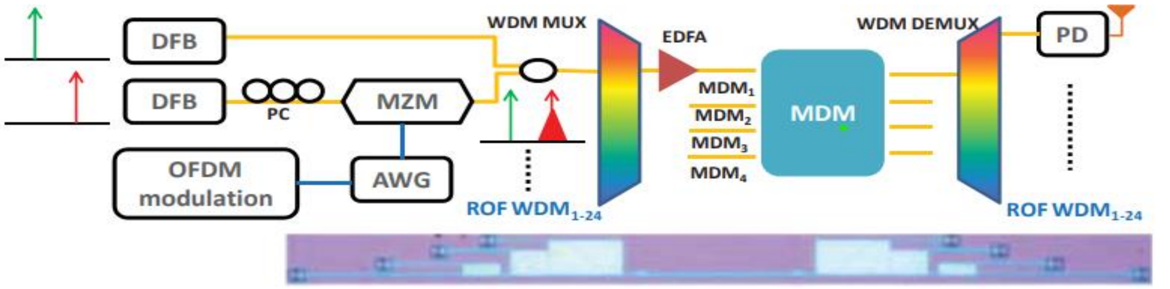

Fig. (8): Experimental setup of 4x4 SiPh based RRH evaluation [25].

3.1.5 Generalized Frequency Division Multiplexing (GFDM)

Regarding complexity and Out of Band (OOB) emission, the GFDM has been presented as a promising 5G solution [38]. It includes a non orthogonal waveform which for transporting M-ary quadrature amplitude modulation (M-QAM) symbols, sub symbols, and subcarriers are utilized. Flexibility is another key advantage of GFDM, to cover 4G technology this waveform might be altered [39]. Forward Error Control (FEC) has been employed by the developed GFDM transceiver to increase data strength against channel communication interference. Convolutional, polar codes, and poor density check parity can be employed with rates of 1/2, 2/3, 3/4, and 5/6. Two correlated kinds of signals are produced when the modulated signal is performed to a time-reversal space-time coding scheme. Two antennas could be fed by this procedure which is separated by some wavelengths so to utilize diversity gain from multi route channel at the receiver. Also, to enhance strength against the multipath channel, a Cycle Suffix (CP) and Cycle Prefix (CP) are presented to the signals. In addition, nonlinear distortions arise due to an electrical amplifier at the RF front end and are reduced by implementing a Digital Pre-Distortion (DPD) scheme. In another word, the electrical amplifier transfer function is identified via DPD and compels an opposite response, targeting the output linear action. The input level will be normalized by an automatic gain control on the receiver side, the transmitter reverse process is performed after synchronization and channel estimation process. The QAM de mapping is fulfilled via the GFDM demodulator and transmits received bits to the channel decoder that furnishes only related information to the Ethernet interface as shown in Figure 9 **[40].**

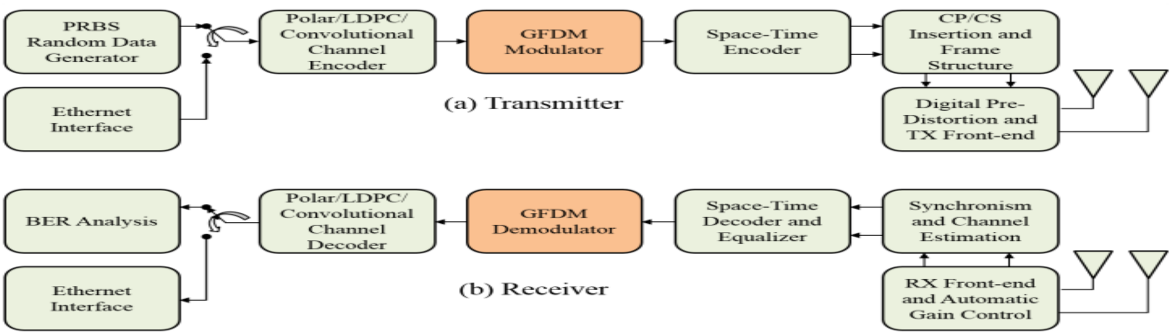

Fig. (9): Block diagram of GFDM based 5G transciever [40] .

Depending on GFDM and multi Gbit/s **[41]** reported the implementation of a fiber-wireless 5G network. DD-MZM was operated to transmit two RF signals concurrently utilizing two 5G nominee bands, particularly: 700 MHz band which supercell is applied for rural access; 26 GHz band which is provided for femtocell with 2 Gbit/s capacity. Also, the broadband 26 GHz signal has been provided via a vector signal generator. A lower frequency signal is generated with lower small out-of-band emission via the Brazilian GFDM-based 5G transceiver. The principal benefit of utilizing DD-MZM is to reduce interference between RF2 and RF1 which is introduced by the nonlinearity of the modulation process. Independently, clear RF signals are modulated at its bottom and upper arms with optimized and cleared bias voltages. After the two modulated signals are transmitted by a 12.5 km fiber optical link, a wideband PD is used to recover the two RF signals and then will be segregated via a diplexer. Afterward, two electrical amplifiers are performed for bands to maximize the power that will be radiated by both antennas, namely 25 and 13 dBi gain of horn antennas, 9 dBi gain Yagi-Uda, and panel antennas for transportation and reception in the 26GHz band, and 734 MHz bands respectively. In this manner, the implementation of a rural supercell has been done with 734 MHz signals, although a high capacity has been accomplished in the 26 GHz band as exhibited in Figure 10.

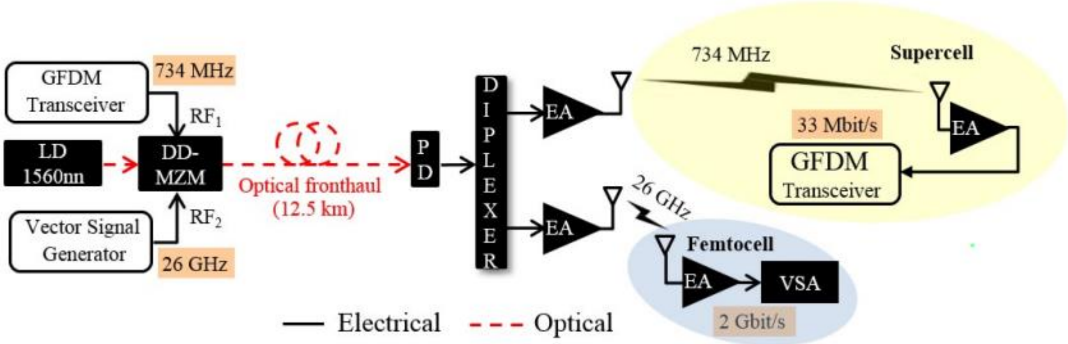

Fig. (10): Proposed block diagram of Multi-Gbit/s and GFDM based fiber-wireless 5G network concept [41] .

3.2 Parallel Intensity Modulation (PIM) / Phase Modulation (PM) Transmitter

In intensity modulation, the intensity of an optical carrier is modulated via microwave signal and after fiber transmission, a single photodetector detects the modulated signal. For this case, an external modulator is utilized like an EAM, MZM, however also direct current modulation of the semiconductor light source is possible. Then, electrical down conversion is required, an intermediate frequency $f_{IF} = f_{Rf} + f_s$ is produced from the mixing of an electrical Local Oscillator (LO) at f_{IF} with the electrical signal at f_s , this IFoF felled within the bandwidth of analog to digital converter (A/D) and digital signal processing is utilized to demodulate it in the digital domain as shown in Figure 11**.** For the system that requires huge power of received optical signal so that to maximize the link gain, inadequate dynamic range because of nonlinearity of intrinsic response of intensity modulation, and influences from periodical power fading that occurs due to chromatic dispersion in the fiber distribution, the Intensity Modulation- Direct Detection (IM-DD) would not be the best solution [42]. A system that requires huge power of received optical signal so that to maximize the link gain, inadequate dynamic range because of nonlinearity of intrinsic response of intensity modulation, and influences from periodical power fading that occurs due to chromatic dispersion in the fiber distribution, the Intensity Modulation- Direct Detection (IM-DD) would not be the best solution [42].

Optical phase-modulated RoF links have been presented and proposed as an alternative to IM-DD to offer huge linearity and small distortion for transmitting high-speed wireless signals.

By Utilizing a phase modulator at BS, the phase of the optical carrier is modulated via microwave signal and transferred to the CS through the fiber. The optical field is recovered by utilizing an optical coherent receiver on the detection side. Then, DSP algorithms are used to process the recovered signal in the digital domain and transmission impairments could be compensated such as beating noise from the source of two lasers or fiber chromatic dispersion. Also, integrating WDM Passive Optical Network (PON) with phase modulation provides flexibility in wavelength choosing given via coherent detection. Moreover, Photonic Down Conversion (PDC) could be performed in a more flexible way via producing a pulsed LO optical source that is free from fiber transmission link, meriting from low jitter, and high stability of optical pulsed sources [43].

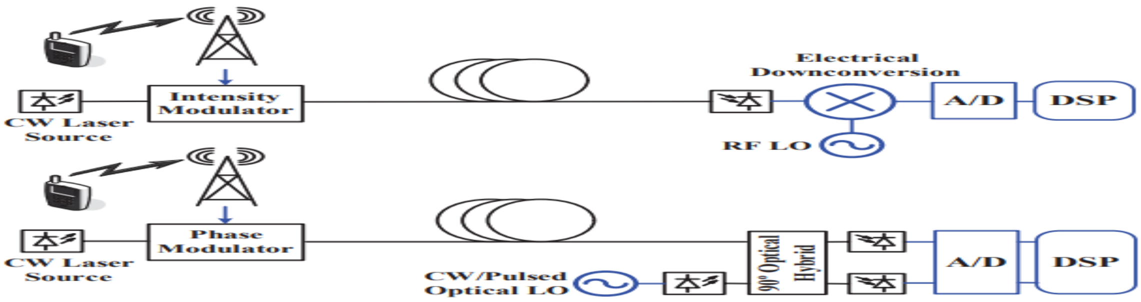

Fig. (11): Block diagram of two various kinds of ROF link: in the upper IM-DD with external modulation, in the bottom phase modulation with digital coherent detection [43].

Ishimura, Bekkali [44] introduced PIM/PM transmitter configuration for large-capacity mobile fronthaul communication. The phase relationship between the lower and upper sideband is changed because of chromatic dispersion. After the IM signal is transmitted through fiber at a certain frequency, because of the phase alteration a transported IM component becomes PM. A phase modulating signal could not be detected by the photodetector in the frequency which component loses. This is the main cause of RF power fading. Also, there is a complementary relationship between IM and PM. This means that even though RF power fading severely distorts the IM signal, the distortion will be compensated by the PM signal as shown in Figure 12. Multiple radio signals are combined on the IF band at the transmitter side. In the procedure, the decision has been done as to which modulator should be utilized for every IF signal. For example, IF signals in bands C and A could route to IM due to frequency areas that do not contain the null point. On the other side, null points will individually degrade bands B and D if they are assigned to IM. But, if the bands are assigned to PM, the maximum response will be attained around the two bands, these bands could be transported without RF power fading affecting them. The null points always could be avoided by the null points, because either PM or IM has a better performance than the other as long as the exact frequency response of PM and IM are recognized prior to transportation [44]. By using this concept, 14 x 1.2 GHz OFDM signals are transmitted over 20km SMF by utilizing the parallel IM/PM transmitter and attained a common Public Radio Interface (CPRI) equivalent data transmission rate of 1.032 Tb/s. 20 GHz total bandwidth of IFOF signal was achieved. The available bandwidth was limited to around 10 GHz without the transmitter [45].

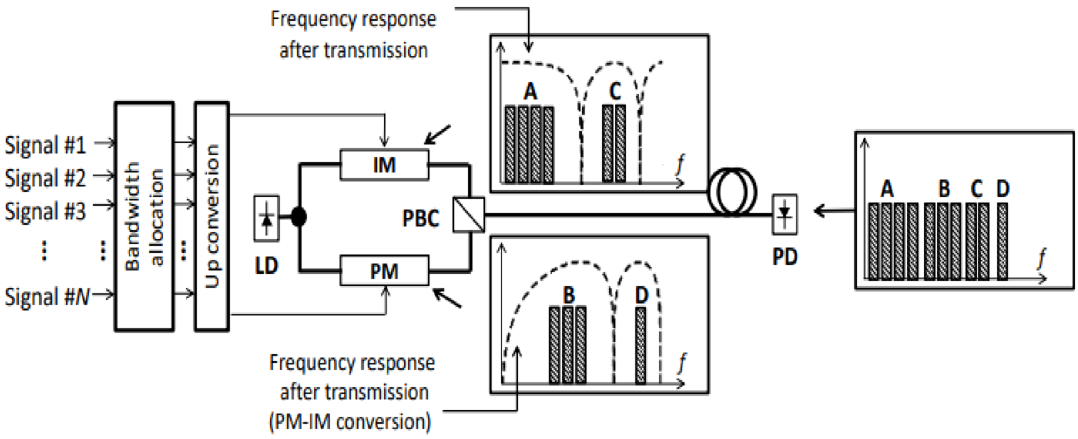

Fig. (12): Architecture of IFOF transportation system with parallel IM/PM transmitter after [44].

3.3 Optical Millimeter-Wave (Mm wave) Generation Techniques

For high-speed indoor communication in 5G networks, it is ordered to move the frequency spectrum to the higher frequency mm-wave band which is ranging from 30-300 GHz to support the growing traffic demands and data services. It has a lot of advantages such as easy deployment, power capacity, and has the ability to the environment. The RoF network needs to be supported to realize signaling [46]. The mm-wave carriers might be produced from the RF local oscillators; however, this is suitable only for low frequencies as the efficiency reduces with high frequencies. But, the phase modulator or frequency response of MZM limits the generating of optical Mm wave signal above 40 GHz. So, the optical generation of signals above 40 GHz is the area of interest. In the optical domain, there are several techniques to generate Mm wave signals such as direct modulation, external modulation including intensity or phase modulation, optical heterodyning including Optical Phased Locked Loop (OPLL), Optical Injection Locking (OIL), and hybrid optical injection phased locked loop, and Up-conversion techniques [47].

3.3.1 Direct Modulation

It is the eldest and most inexpensive method applied for an Mm-wave signal generation as the semiconductor laser is directly modulated and PD is utilized to recover the generated Mm-wave signal [9]. Also, it changes the transferred information into an electrical signal and modulates the optical power, therefore electrical signal could be transported on the optical carrier [48]. Mainly, RF signals are superimposed on the DC bias of laser by a direct modulator and then modulated on the optical light signal. At the remote end, the electrical Mm-wave signals are generated after PD detection. After unnecessary noise is filtered by Band Pass Filter (BPF), an EA amplified the generated electrical Mm-wave signal and is transported to the user through the antenna as exhibited in Figure 13 [46].

Even though this method is uncomplicated in configuration, it is only appropriate for generating low-frequency signals as the modulating signal is limited by the modulation bandwidth of laser e.g. 40 GHz which above this frequency chrip, unwanted noise is produced and show nonlinear characteristics resulting in fewer stable output [46].

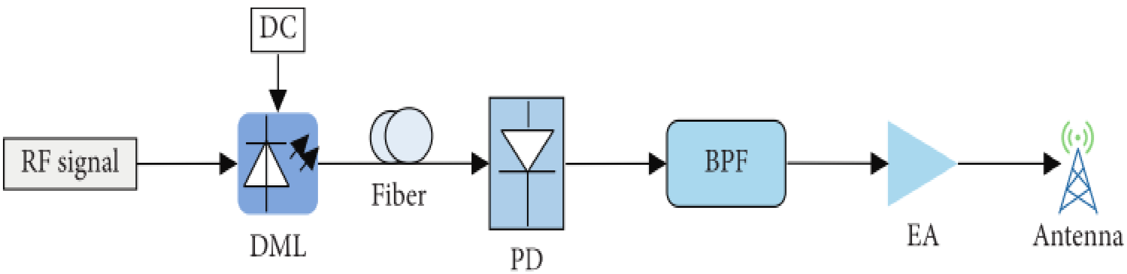

Fig. (13): Block diagram of directly modulated laser (DML) [46]

3.3.2 External Modulation

In this modulation scheme, the Mm-wave signal is generated via using the link between the laser source and external modulator as shown in Figure 14. Also, it has been driven by an RF signal to generate a light band that carries information. Then, the Mm-wave signal is generated by this light band at the beating frequency in PD [49]. External modulation schemes could apply multiple modulators aggregated with frequency multiplying technology to generate Mm-wave signals [50]. The essential working principle of this method relies on the generation of higher-order harmonic outcoming from the modulator nonlinearities in transportation [51]. The power of harmonics is managed from the modulation index and bias voltage whilst LO drive voltage is utilized to adjust the amplitude. This reduces the bandwidth demand and helps low drive signals generate huge frequency signals which minimizes the system cost. Relying on the two kinds of modulator approaches applied this method includes phase and intensity external modulation.

In external intensity modulation, the intensity of the signal which is the square amplitude of the signal is modulated as per the information signal and this could be performed by EAM or MZM. An EAM could be simply aggregated with the optical laser source and requires less driving power than MZM [52]. This technique removes the demand for complex circuitry which furnishes huge bandwidth and long-haul transportation without any amplifier. Even though this technique is uncomplicated, it endures fiber dispersion influences, large insertion loss, and distortion because of the intrinsic nonlinearity of modulators. On the other hand, external phase modulation, modulates the phase of the carrier signal by the optical signal. It has an additional advantage over MZM which provides a stable output that they are independent of the problem of bias drifting, therefore do not need dc biasing [53].

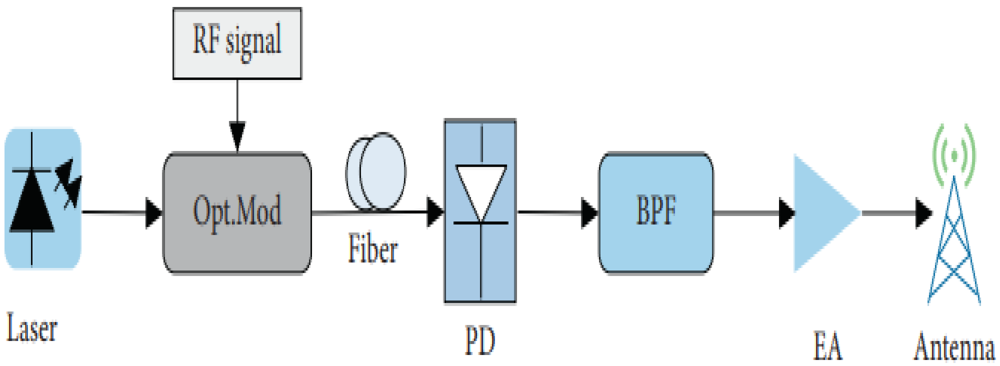

Fig. (14): Block diagram of external modulation after [46]

[54] proposed a novel quadruple method where the optical carrier signal is suppressed to produce an optical Mm-wave signal by utilizing a LINbo3 MZM modulator. This scheme is experimentally presented and the quality of the produced signal is analyzed. The generation of optical Mm-wave has been done by performing optical carrier suppression and a 2.5 Gbaud data transmission rate is done through an SSMF of 60km distance without utilizing an amplifier in BS. The MZM has two separate arms, a phase is changed when voltage is performed into one of the arms and an optical wave moves through the second arm. The phase shift in MZM either generates a destructive or constructive frequency modulation when two arms are reincorporated. In the proposed system, the frequency could be multiplied four times by the iteration method of a 6V bias voltage. Therefore, a quadruple frequency is generated by utilizing the LiNbO3 MZM modulator which is an intensity modulation utilized to maximize the modulation frequency of the carrier signal via changing the bias voltage of MZM and transported through a 60 km SSMF by preserving the same frequency to the BS without utilizing an amplifier as exhibited in Figure 15.

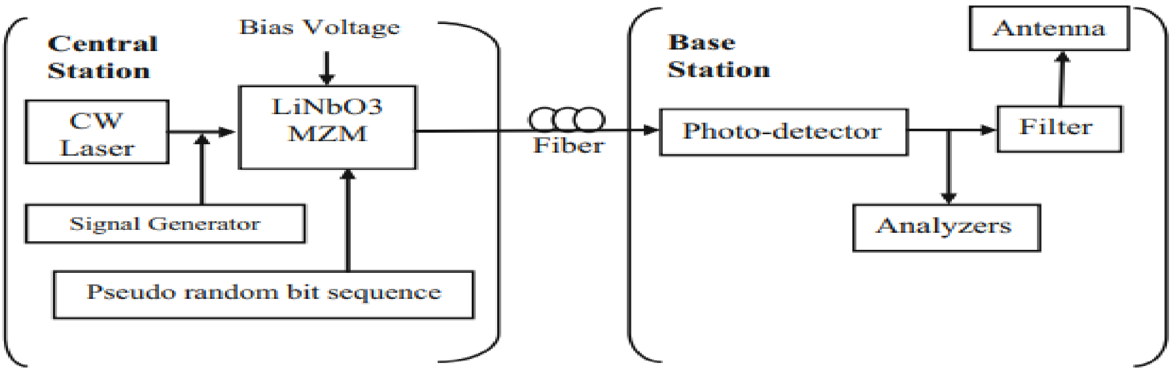

Fig. (15): Block diagram of generating mm wave signal from LiNbO3 mach zehnder modulator [54]

3.3.3 Optical Heterodyning

Optical heterodyning also is an effective signal for producing Mm-wave signal. The optical signal that is emitted by an independent laser with modulated signal penetrates the PD. Square-law PD is utilized to beat the frequency of two signals [55]. Mm -wave signal is generated by essential idea of optical heterodyning beat frequency whose carrier frequency ω_1 and ω_2 is the difference of two lasers frequency $\omega_1 - \omega_2$ as shown in Figure 16 **[56].** Generating high-frequency signals with this technique is beneficial with Carrier Noise Ratio (CNR) and higher link gain. Also, make the system less responsive to chromatic dispersion when one of two optical carriers is modulated with an information signal. As the phases of two optical signals are not correlated, this technique endures the phase noise of the laser. Utilizing techniques such as OIL, OPLL, and aggregation of OLL and OPLL could minimize the sensitivity toward phase noise and enhances the signal quality [54].

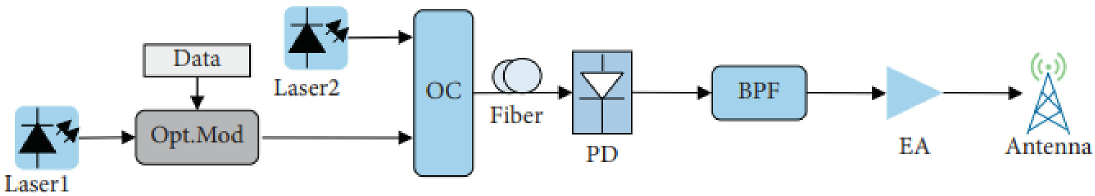

Fig. (16): Block diagram of the optical heterodyning scheme [46]

Based on optical heterodyning a 5G Mm-wave RoF optical fronthaul system has been presented by **[57]** which an externally injected gain switched Distributed Feedback Laser (DFB) has been utilized. five signals of Universally Filtered-Orthogonal Frequency Division Multiplexing (UF-OFDM) are transported over 25 km of SMF link and 28 GHz wireless antenna link. Transmission performance lower than FEC is attained with an entire transmission rate of 4.56 Gb/s for the whole five bands. A small linewidth coherent comb source is produced via an externally injected gain-switched DFB that is utilized to exhibit a 28 GHz 5G mm-wave ROF system. The proposed system is utilized an externally injected gain-switched laser for generating Optical Fiber Comb (OFC) with tunable FSR and wavelength. Mm-wave frequencies are generated by exploiting photonic techniques like optical heterodyning which is appropriate and efficient with fiber convey infrastructure.

An analog RoF sending five signals of UF-OFDM around 60 GHz over 25km SSMF was experimentally presented by **[58]** with optical heterodyne. Performance less than the FEC limit is attained for a data transmission rate of 4.56 Gb/s. Extremely, as a comparison to OFDM, (UF-OFDM) is an OFDM inspired' waveform whose sub-band filtering presents low OOB emission, permitting for increasing spectral efficiency in mutli-band systems. In the proposed system, an OFC with tunable free spectral range and wavelength is produced by using gain switching of a DFB laser that permits flexible and stable operation across the Mm-wave range. Also, one of the data sidebands is fully suppressed by utilizing a tunable Optical Band-Pass Filter (OBPF) and carrier power is decreased to generate a Carrier Suppressed Single-Side Band (CS-SSB) signal. DE-correlation pre-compensation has been used to minimize RF phase noise permits for the excellent performance of ~5% EVM on every channel. The result presents that, the demand for an effective mM-wave 5G signal is the correlation between optical carriers that employ photo-mixing for RF generation as shown in Figure 17.

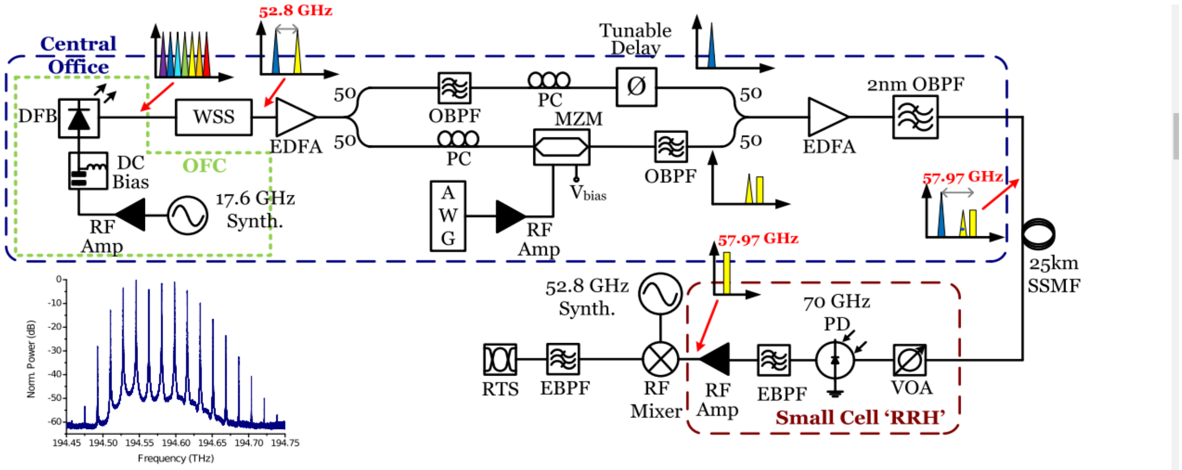

Fig. (17): Experimental setup of 5G Mm-wave fronthaul generation by optical heterodyning [58]

3.3.4 Optical Up Conversion

In the upconversion optical method, an IF signal is transported to the BS through a fiber optical link. Then, the IF signal is upconverted to an RF signal, and a local oscillator is utilized to produce the Mm-wave carrier signal at BS. Then, the IF signal is upconverted to an RF signal and a local oscillator is utilized to produce the Mm-wave carrier signal at BS. Broadly, there are three principal methods classified for attaining optical up conversion based on MZM or photodetector nonlinearity and wavelength conversion. These techniques depending on wavelength conversion rely on nonlinearities dwelling in RoF link components and could be achieved with optical switching. But the transmitted signal frequency is varied by MZM based up conversion without changing LO frequency and generates a WDM signal through a single modulator, therefore decreasing the cost of the system[9].

Depending on MZM nonlinearity, the transference of MZM exhibiting non-linear characteristics tends to generate intermodulation and harmonics products. These products of inter-modulation and harmonics are used for optical up conversion through the optical K-tupling technique and Kth harmonic is the frequency of photo detected output signal of LO frequency.

Frequency up conversion depends on wavelength conversion concerns with the nonlinearity of Semiconductor Optical Amplifier (SOA), photodetector, and optical fiber. Based on fiber nonlinearities, the fiber refractive index that depends on the optical power presents some nonlinearities such as SPM, FWM. For up conversion, this fiber nonlinearities could be used for example for generating SPM assisted techniques, highly nonlinear Dispersion Shifted Fibers (DSF) are performed up to a certain length. When shifting occurs for wavelength from zero-dispersion 1300 nm to 1550 nm, these fibers show a nonlinear refractive index [20]. Also, nonlinearities affect SOA as optical fibers do, gain saturations affect them. Therefore, the phenomena of Cross Gain Modulation (CGM), FWM, and SPM from SOA could be utilized for optical up conversion. In addition, PDs also show nonlinear behavior which could be manipulated for optical up conversion via modulating its bias voltage. SOA-MZI is applied to aggregate the phase modulated signal into an intensity modulated signal [20].

[59] experimentally demonstrated a 24 Gb/**s** analog IFoF wireless V-band over a 7km fiber distance and 5m wireless length applying a digital 6-IF carrier stream that attaining a capacity for multi band 5G fronthaul networks with a variable developed modulation format. In this communication based on MZM, a six-band Mm wave/IFOF has been transported with an aggregated symbol rate of 1Gbaud 16QAM data stream at 60 GHZ by utilizing IM/DD for downlink and uplink communication. ILX laser diode with 10 dBm saturation output power control a DFB laser diode. The output of DFB was joined to the input of a LiNbO3 MZI modulator which is biased at its quadrature point with a Vπ of 3.5V, therefore electrical signal with 2.5v VPP voltage swing drive the MZI modulator to be operated in its linear regime. The channel was digitally up converted to 3.6 GHz central IF by using an Arbitrary Waveform Generator (AWG).

Then, the synthesized electrical IF signal was aggregated with the output voltage through Bias T, before being driven to the MZI modulator. At the output of the modulator, the optical signal was transmitted through 7km SMF which variable optical attenuator followed, and a 99/1 power tap to handle the optical power and monitoring process. The output of the PD and a Transimpedance Amplifier (TIA) with 0.7 A/W responsivity was fed to a pair of antenna transmitter (Tx) and receiver (Rx) radio equipment by siversima for wireless transportation across the 5m link. Also, up conversion has been done for the IF signal to 57-64 GHz band. At the receiver side, the Mm wave signal will be received by the horn antenna, it will be down converted back to the IF signal before feeding to a digital real-time oscilloscope [60]. Also, the reverse operation has been demonstrated for uplink communication as shown in Figure 18.

A brief description of various capacity enhancement techniques has been presented in Tables 1, 2.

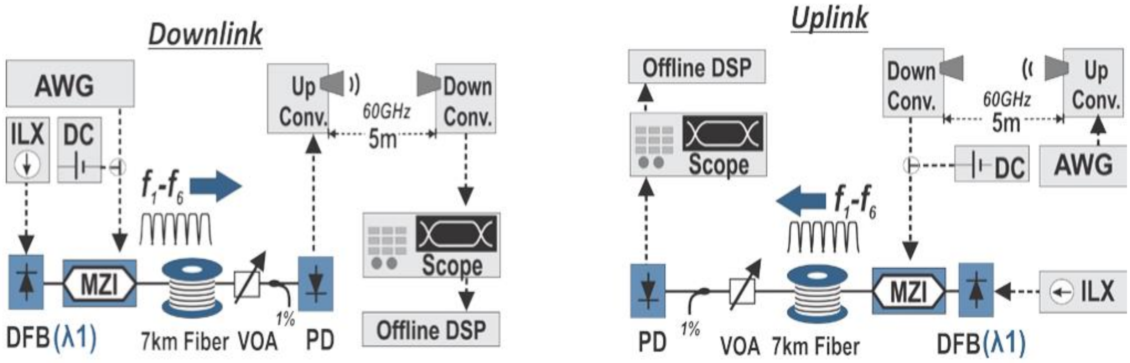

Fig. (18): Experimental setup for the evaluation of uplink and downlink scenario [59].

Table (1): Literature review based on Polarization Division Multiplexing (PDM), Mode Division Multiplexing (MDM), Generalized Division Multiplexing (GFDM), and Wavelength Division Multiplexing (WDM) techniques.

References	Technique	Achievements
[7]	Designed fiber optical link based PDM.	• It can be observed that With HOA longer reach up to 130km can be attained. • With HOA acceptable value of Q-factor, BER, SNR attained at 130km for 16 and 64 QAM
[23]	SiPh-based RRH with 4x4 MDM and 24 channels of WDM has been proposed.	• −15 dB worst crosstalk was observed at MDM output channel 1 when optical signal passed through MDM input channel 2. • It can be observed that, high powers are achieved around 1555 nm in RoF channels due to waveguide grating coupler dependence. • BER= 3.8 x 10^-3 at the FEC threshold • Due to crosstalk, receiver sensitivity is from -14 dBm to -10 dBm.
[41]	Presented multi-Gbit/s and GFDM-depend on Fi-Wi 5G network with 256,16 QAM	• Throughput from 1 to 2 Gbit/s has been provided for femtocell with EVM from 7.8 to 13.8%. • 33 and 22 Mbit/s has been attained for supercell that is implemented in a rural area at a high school (7.51 km away) and a farm (11.48 km away), respectively. • For higher power levels, Modulation Error Ratio (MER) is reduced due to PD and modulation process which is 4.5 dB for PRF = 0 dBm and only 0.6 dB for PRF = -5 dBm.
[44]	High capacity IFoF signals transmitted with OFDM utilizing parallel IM/PM transmitter.	• Simple architecture • Prevent RF power fading without utilizing DSP • EVM of RF input signals to PM and IM are around 5-6%
[26]	Based on the DWDM-Rof system with MZM,1.28 Tbps was generated. DCF and EDFA have been used to optimize performance.	• Minimize the influence of chromatic dispersion and boost the signal. • Higher performance with 60 km length with a maximum Q factor of 25.44. • Degrade the performance and cross talk raised with increasing distance
[28]	DML depend on WDM-RoF with resource allocation flexibility	• Maximum achievable link distance for 4-QAM is 40 and 39 km for analytical and simulation models respectively,31 and 29 km for 16-QAM, and 21 and 20 km for 64-QAM. • The difference between simulation and analytical results is 1% due to disregarding fiber dispersion in the analytical model. • Threshold RMS EVM is satisfied experimentally under low and high traffic load.
[29]	OFDM based IFoF wavelength division multiplxing with ROADM and PIC has been employed.	• The longest length in which BBU could be located from the hospot areas is up to 4.8 km with acceptable EVM performance. • Sufficient power budget • Data rate up to 12 Gbps for every wavelength was attained for transportation 4-IF band OFDM 64-QAM signal with acceptable EVM.
[25]	WDM-depend on RoF system with Hybrid DCF and FBG has been proposed	• As power reduced to -15, the FWM generated which reduced SNR. • As the power minimized to -5, the BER decreases and with alteration input power to -15 BER increased. • Optimum and worst eye diagram observed at -5 and -15 dBm respectively for Chanel 1,8 and 16. • Q-factor has been improved up to 16.51% and a clear eye diagram has been observed with increasing channel separation from 50 to 100 GHz at -5 dBm.

Table (2): Literature review based on Subcarrier Multiplexing (SCM) and mm-wave generation techniques

References	Technique	Achievements
[14]	Proposed RoF system based WDM-SCM with QAM-OFDM	• Power consumption reduced with 16-QAM • It can observe that WDM/SCM with 16-QAM-OFDM has a better performance than the other modulation technique with Symbol Error Rate (SER) equal to 10^-9. • For same bit error rate, RF signal power increased with increasing level of M-QAM • high capacity achieved.
[32]	RoF based SCM with DPSK has been proposed.	• Better results have been achieved with FBG and DCF as compared to OPC. • Maximum Q factor is observed with symmetrical DCF when RoF based DPSK with SCM is implemented at 20Gbps bit rate and transmission length from 50 to 200 km.
[33]	Proposed An Enhanced model of WDM /SCM based RoF system with no equal channel spacing	• By using a switching voltage of 6 V = Vπ and a bias voltage of 3 V = 12 Vπ, OSSB, and not equal channel spacing lowest BER was achieved. • System performance is reduced because of the influence of ASE noise. • ASE noise is reduced by locating EDFA 1km away from the transmitter while the overall link length is 10km.
[58]	transportation of five bands of UF-OFDM has been presented by the optical heterodyning technique.	• By utilizing the tunable delay, accurate phase matching is obtained with -6 dBm received optical power. • Better performance is attained for all channels which are below 7% FEC limit of 3.8 x10 ^-3. • RF phase noise has been reduced when the optical signal beating at the 70 GHz photodetector
[57]	5G signal transmission of five bands of UF-OFDM over 25 km of SSMF and wireless link proposed by utilizing an externally injected gain-switched DFB laser.	• At higher frequencies, attenuation occurs due to higher frequencies • Performance of the higher frequency channels has been reduced due to bandwidth limitation of RF amplifiers • Best performance has been demonstrated at received optical power at 3 dBm.
[59]	By utilizing the MZM modulator and V-band directional antennas a DSP aided A-RoF architecture presented	• For a single channel, the performance of mm-wave propagation degraded which presented an additional EVM penalty of 5 and 4.1 for uplink and downlink configuration respectively. • Performance degraded due to increased propagation loss of the v-band. • As compared to a single channel, the average EVM penalty presented by 6 channels was 3.5.

(4) DISCUSSION

The different techniques occupied for capacity enhancement in RoF system as discoursed in the prior section and comparison between them has been done based on some performance metrics including several channels, maximum data transmission rate, channel spacing, and capacity (Throughput) as presented in Table 3. After all enhancing techniques have been compared, hybrid MDM with WDM appears to be the most promising technique where SiPh technologies are presented for RoF system to reduce complexity and cost caused due to a huge number of antennas and Remote Radio Heads (RRHs). Maximum capacity has been achieved due to a high number of channels which is 96 where multiplexing of 4 and 24 channels of MDM and WDM are utilized respectively. In addition, MDM furnishes an extra dimension for multiplexing. But at the same time has the disadvantage of high-power penalties which happens in some channels because of higher mode cross talk.

Which higher mode cross talk can be prevented by wider wavelength separation that every optical wavelength is typical and various; space between wavelengths control the channels spacing to prevent the overlapping, which has occurred in the optical carriers. Moreover, the second-best technique was Dense Wavelength Division Multiplexing (DWDM) which is based on 32 channels with high data rates. In addition, crosstalk was overwhelmed due to a smaller number of channels and the wavelength separation between them was less than 200 GHz. It can be concluded that higher channel spacing performs better than small channel spacing.

Subcarrier Multiplexing plays a great role to enhance the capacity and efficiency of bandwidth utilization. As presented in Table 3, the properties of WDM and SCM have been aggregated to attain enlarging capacity. At the same time, overlapping between RF signal that is combined by SCM must be considered and it is more sensitive to phase noise. The data transmission capacity can be improved with optical Mm-wave band techniques including optical heterodyning, Up/ Down conversion, and external modulation but it is more cost and complexity. Also, has some disadvantages that are consociated with the band around 60 GHz associated with the higher losses in free space and light blocking of the walls at these frequencies. In a conclusion, enhancing capacity by utilizing any techniques parameter such as cost, complexity, Cross talk between channels, performance of the system, phase noise, and dispersion must be considered.

Table (3): A comparison of existing RoF system Techniques

References	Techniques	No. of Channels	Maximum bit rate Gbit/sec	Capacity	Minimum channel spacing
[26]	DWDM	32	40 Gbps	1.28 Tb/s	<200 GHz
[28]	WDM with 4,16,64 QAM	20	2 Gbps for 4-QAM 4 Gbps for 16-QAM 6 Gbps for 64-QAM	20 Gbps 80 Gbps 120 Gbps	100 GHz
[29]	OFDM based IFoF WDM with ROADM	4	12 Gbps	96 Gbps for duplex communication	100 GHz
[25]	WDM	16	10 Gbps	160 Gbps	50 and 100 Gbps
[14]	WDM-SCM with 4,16,64 QAM-OFDM	8	20 Gbps	160 Gbps	100 GHz
[32]	SCM with Differential Phase Shift Keying (DPSK)	3	20Gbps	-	-
[33]	WDM /SCM	4	-	-	-
[7]	PDM with 16 and 64 QAM	1	5,6,7,8 Gbps	-	-
[23]	SiPh-based RRH with MDM and WDM	96	48.01 Gbit/s to 51.61 Gbit/s	4.781 Tbps	60 GHz
[41]	multi-Gbit/s and GFDM-based fiber-wireless 5G network with 256 and 16 QAM for GFDM	1	5,22,33 Mbps for QPSK,64,256 QAM for high school	33 Mbps for outdoor 2Gbps for indoor	-
[44]	OFDM utilizes Parallel Intensity /Phase Modulators (IM/PM) transmitter.	14	-	1 Tb/s	-
[58]	UF-OFDM with optical heterodyning technique.	5	0.912 Gbps	4.56 Gb/s	52.8 GHz
[57]	UF-OFDM with an externally injected gain-switched DFB laser.	5	0.192 Gbps	4.56 Gbps	27.83 GHz
[59]	a DSP aided A-RoF architecture presented to transport 6-IFOF 16-QAM channels with optical Up/ Down conversion	6	4 Gbps	24 Gbps	-

(5) CONCLUSION

The growing number of mobile devices desiring applications of the internet has attracted the inspection of various possibilities and methods for attaining a higher capacity of interchanging information with enhanced coverage potential. This paper presented a brief review of a recent study that is based on capacity enhancement in the RFo system. This paper covers a detailed study of RoF in 5G explaining its Architecture, kinds, applications, signal generation, and limitations in detail. The various enhancing capacity techniques in radio over fiber system including multiplexing, Optical Mm-wave generation, and PIM/PM have been presented and evaluated. Also, based on the techniques that mentioned above, several methods and structures to realize data transmission with huge capacity are listed and reviewed. In addition, comparison between them has been done in terms of a number of channels, channel spacing, throughput, and maximum transmission rate as shown in Table 3. Also, the greatest promising techniques have been presented and explained.

It can be concluded that with enlarging capacity several metrics must be taken into account such as overlapping between channels and RF signal, cost and complexity of the system, dispersion, and phase noise which deteriorate the performance of the system. To sum up, the RoF system in the area of communication in the upcoming decades will persist to be a research hotspot for the adepts. Due to its ultra huge-speed and high wideband transportation characteristics and its powerful flexibility in access, its applications are very costly, but, with rise of length and constant desire for communication capacity, the transmission system still has less or more inadequacy, and still, there are much unexplored domain to be analyzed.

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