Design and Implementation of 1.28 Tbps DWDM based RoF system with External Modulation and Dispersion Compensation Fiber

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Abstract. The improvement of 5G networks started in 2019 and is commonly accepted to bring changes not restricted to individuals’ day-by-day life. The interconnection between the nodes of 5G network is realized through the utilization of optical transceiver modules and optical fibers. The most interesting part in the 5G communication network is the communication between the Central Office (CO) and the Base Station (BS), which has been widely investigated by several researchers to enhance and optimize such network performance. As a result, in this paper we demonstrate, design and implemented: a) based on Dense Wavelength Division Multiplexing (DWDM Radio over Fiber (RoF) system and by using the software of Optisystem 17.1 version. Such system is considered a 32X40 Gbps of data transmission for higher speed transmission system towards the Tera bit per second (Tbps) communication. The channels of 1, 4, 8, 12, 16, 20, 24, 28 and 32 were selected as samples for the investigation. The performance analysis would be based on the parameters of the eye diagram, (Quality Factor) Q-factor and Min Bit Error Rate (BER) and for distances of 60, 120 and 180 km respectively. Analyzing results indicate a higher performance system toward the 1.28 Tbps of data rate transmission.

1. Introduction
The huge development of internet traffic and the advent of latest applications could be considered as the most interesting aspects for providing higher capacity with lower cost technologies based fiber optic communication. The basic idea of such technologies based fiber optic communication was to perform transmission between two nodes and by using light source [1]. Fiber optic based communication system could be considered as the backbone of the high speed infrastructure which could provide higher capabilities such as enormous bandwidth, lower attenuation effects and distortion, lesser usage in material, lower utilization power, higher data rates and laser effective costs [2]. Such communication system could be used for longer distance transmission. However, in some application as increasing the transmission distance the power should be increased to satisfy the entire distance and several nonlinear effects would be appear as increasing the optical transmitter power [3]. Radio over Fiber (RoF) system could be considered as one of the most interesting technique for wireless access network, in which it could be utilized to transmit the millimeter waves over the fiber optic links.
for short and long distances [4]. RoF can be defined as an analog optical link which transmits modulated RF signals. In addition, such technology uses optical fiber links to distribute RF signals from a central location to the Remote Antenna Units (RAUS). It transmits RF signal uplink and downlink. It transmits an RF signal to the central-station (CS) from the base-station (BS) and vice versa [5]. Furthermore, it has several advantages in the adaptability and flexibility of mobile communication to support the 5G mobile communication system the required services towards the Terabit data rate [6]. RoF has several characteristics related with increasing the channel capacity and decrease both the power consumption and implementation costs, which make them suitable for the demand of wireless network communication [7].

The Wavelength Division Multiplexing (WDM) technique has been used widely in optical communication system for gathering group of optical carrier signals, which have different wavelength into a single optical fiber link. The utilization of WDM could achieve higher data rate, larger bandwidth and lower costs [8]. The emerging of Dense-WDM (DWDM) has raised the significant of WDM and increased its efficiency in bit rate and capacity, where a huge bandwidth would be used followed by using different optical amplifier without the need for electrical and optical converters [9]. Furthermore, the utilization of Dispersion Compensation Fibers (DCF) to minimize the impact of the Chromatic Dispersion (CD), would increase the possibility of performing longer transmission fiber optic communication [10]. Despite all these techniques attempts to raise the fiber optic performance. However, there is still a lot of methods and prospects to be investigated and tested.

2. Related work

Researchers and industries for our investigated paper field have proposed many works. For example, in [11] a DWDM of 32 channel based Passive Optical Network (PON) has been proposed by using the software of Optisystem. The proposed system could achieve a bit rate of 3 Gbps using both data format methods of ("Non-Return to Zero (NRZ) and Return to Zero (RZ)") and with a total distance of 40 km. The Bit Error Rate (BER) achieved for their proposed system was < 10-12. Additionally, in [12] researchers proposed an investigation for a RoF based system with various length of (5, 20, and 60) km of fiber cable and various cases of channel spacing. The system consists of four transmitters with a first selected frequency of 1552.50 nm and a channel spacing of 0.4 nm between the other three channels. The bandwidth selected was 10 GHz, and the input bit rate was 1 Gbps. The parameter of the eye diagram, Q-factor, and Min BER would be analysed by using optisystem software. Furthermore, a methodology for enhancing the quality of the received signal for the proposed system by utilizing the optical amplifier after the transmission of the case of 60 km distance. Such optimization has increased the efficiency of the proposed system. In addition, another work proposed by authors in [13] with two-channel has been designed for the RoF system by using Mack Zander Modulator (MZM) as an external modulator. Besides, it has been selected the Q-factor as an evaluation metric for their proposed system and based on different distances of (10, 20, and 30) km. Furthermore, the evaluation has been carried out by considering different extinction ratios ranges between (10-30) dB with a spacing of 5 dB. Results obtained showed a direct correlation between the extinction ratio and Q-factor, while a reverse relation has been found between the Q-factor and the distance. The optimum results were achieved for the case of using 30 dB and 30 km of extinction ratio and distance respectively. Meanwhile, in [14] it has been proposed a scheme for four-channel DWDM based on the use of the Free Space Optical (FSO) channel. Results obtained would take into consideration different weather conditions with a distance length of up to 5 km. The effectiveness of their system was for a distance of up to 2 km, while for a long distance the Q-factor would be significantly reduced until reach zero. Moreover, in [15] authors demonstrated an investigation for the DWDM system using Roman Optical Amplifier (ROA), where 80 channels were included with the investigation. The Min BER and Q-factor were the basis of their investigation and with various channel spacing ranging from 20 GHz to 100 GHz. results have concluded that utilizing the 100 GHz of channel spacing has achieved the best overall performance and results. In [16] researchers designed and evaluated a scheme based on full-duplex communication between four BS and
one CO. Their proposed system works for 5Gbps data transmission and a distance of 90 km. The proposed scheme has achieved a Q-factor of 30.8. However, such a scheme has achieved a lower bit rate, which needs to be enhanced to meet the requirement for 5G systems.

3. System based methodologies

3.1 Optical Fiber Communication System
Fiber optics can be defined as a medium utilized for handling the information movement from one location to another in the form of a light based signal. The fiber optical cable carries the light, then the receiver will receive the light signal and reconvert it back into an electrical based signal, and thereby the fiber optics is not considered as an electrical medium in nature [9]. A basic communication system based fiber optic consists of a transmitter device that converts an electrical signal into an optical form. The basic diagram of such systems can be shown in Figure 1, in which it includes a transmitter circuitry, light source, fiber optics cable, and detector and receiver circuitry [17].

![Figure 1. Overview on the Basic diagram of fiber optical communication system](image)

3.2 Radio over Fiber (RoF)
The General idea of RoF technology is to perform the modulation process for the light with a radio frequency signal and transmit it over a fiber optic link. The demonstration of RoF based system can be seen in Figure 2, in which the Control Station (CS) is used for the generation of the signal. In this, the RF signal is transmitted with the help of an optical fiber link. At the Control office modulation and signal processing is used to build the baseband signal. There is negligible Attenuation loss in this transmitted signal then, this transmitted signal is detected at the BS. At the Base Station Unit (BSU) the operations of both conversion the electrically to optically (E/O) and optically to electrically (O/E) take place [18]. The signal transmission between the Wireless Terminal Unit (WTU), BSU, and the user takes place with the help of an antenna which is placed at the base station unit. Communication between BSU and CS takes place with the help of an optical signal.

3.3 Wavelength Division Multiplexing (WDM)
WDM could be defined as a type of Frequency Division Multiplexing (FDM) based technique in which the optical signal with various wavelengths would be combined, transferred, and then separated at the end of the transmission side. Such a technique is required in the case of the availability of several channels. Hence, the system capacity would be increased in a significant manner [18]. The WDM could also be denoted as a passive device that performs the main task of combining and recombining different wavelengths over a single fiber cable. WDM could provide an effective way to optimize the capacity of the RoF system and improve the total number of BS that was powered by a single CO. [19]. The basic concept of WDM technology can be illustrated as in Figure 3.
Furthermore, DWDM has been classified into two types by the International Telecommunication Union (ITU) organization. The most interesting type was the DWDM, in which it would be performed for longer distances with larger data capacities, which would make them preferable. DWDM utilized a large number of channels, and a small channel spacing ranging between (12.5-200) GHz. The obtained bit rate would higher than 100 Gbps. In several cases, the Time Division Multiplexing (TDM) could be considered as an alternative to WDM in which different channels would be separated based on the arrival time [18].

### 3.4 WDM based RoF system

The usage of WDM into RoF prompts a huge expansion in the inclusion territory and upgrades the general limit of the current optical networks and offers the advantages of high data rate and expanded versatility. A WDM-RoF-based system is proposed for signal demodulation which has forestalled the need to plan and introduce two separate networks. The concept of the distribution RoF-WDM system can be demonstrated in Figure 4 [4].
4. Proposed DWDM-RoF system

The proposed scheme of this work would consist of 32 Radio Frequency (RF) transmitter to transmit the signal over Single-Mode-Fiber (SMF) link at various distances. For the receiver, it would consist of 32 remote stations. The simulation of the proposed system would be performed by using OptiSystem software 17.1. This software could provide higher reliability and adaptability to design, test, and simulate different fiber optic systems. Figure 5 clarify the proposed 32X40 DWDM-RoF system.

A- Transmitter part

The transmitter part consist of an optical laser array of 32 element in which each transmitter consists of its channel with its related operational wavelength. The electrical signal is generated via the external modulation block and this block is consists of Pseudo-Random Bit Sequence (PRBS) for binary data generating, then it is handled by using Non-Return to Zero (NRZ) pulse generator to convert the binary data to electrical pulses as a baseband signal. Then the Continuous Wave (CW) laser array would be utilized as a laser source and for each channel then both electrical signal and optical laser signal would be combined by using Mack Zander Modulator (MZM) and as seen in Figure 6. MZM has three ports, where two of them would be input port and the last would be formed as the output. The frequency utilized for each channel started from 191.5 THz and with 0.2 THz frequency spacing, the power selected for CW laser is 0 dBm and a linewidth of 0.1 MHz. Furthermore, the bit rate selected for each channel is 40 Gbps. The utilized multiplexer was with a bandwidth selected of 60 GHz for 32 signal combination link, where each link would connect each input channel.
Figure 5. The proposed DWDM-RoF system for 32 channel
The optically modulated signal would be transferred through the SMF for the selected distances of 60, 120, and 180 km through the use of loop control. The attenuation and dispersion effects would be considered in the performance analysis of our proposed systems by setting it to 0.2 dBm/Km and 16.75 ps/nm/Km. Due to the long-distance transmission, the problem of chromatic dispersion would appear. As a result, the dispersion compensation must be utilized for extending the transmission distances. Thereby, a Dispersion Compensation Fiber (DCF) has been designed for this purpose and as seen in Figure 7.

The Erbium-Doped Fiber Amplifier (EDFA) has been used in this part and as the most conveyed fiber amplifier as its intensification window agrees with the third transmission window of silica-based optical fiber. The center of a silica fiber is doped with trivalent erbium particles (Er3+) and can be productively siphoned with a laser at or close to frequencies of 980 nm and 1480 nm, and gain is shown in the 1550 nm locale. The EDFA enhancement district changes from application to application and can be anywhere between scarcely any nm up to ~80nm. Ordinary utilization of EDFA in broadcast communications calls for Conventional, C-band intensifiers (from ~ 1525 nm to ~ 1565 nm), Long, or L-band speakers (from ~ 1565 nm to ~ 1610 nm). Both of these groups can be enhanced by EDFAs, however it isn’t unexpected to utilize two unique speakers, each improved for one of the groups. The parameters selected form the utilized EDFA were listed in Table 1.

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**Figure 6.** The external modulation subsystem in the transmitter part

**B- Transmission Medium part**

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**Figure 7.** The transmission medium part with DCF
Table 1. The selected parameters of the utilized EDFA

| Parameters of EDFA | Parameter Value |
|--------------------|-----------------|
| Gain               | 10 dB, 5 dB     |
| Noise Figure       | 6 dB            |
| Operation mode     | Gain Control    |
| Power              | 10 dB           |
| Saturation power   | 10 dB           |
| Include Noise      | Yes             |

Additionally, in this part the Dispersion Compensation Fiber (DCF) has been used as a loop of fiber having negative dispersion equivalent to the dispersion of the communicating fiber. It very well may be embedded at one or the other start (pre-compensation methods) or the end (post-compensation methods) between two optical amplifiers or mix compensation. The parameters utilized in the DCF within our proposed system has been listed in Table 2.

Table 2. The selected parameters of the utilized DCF

| Parameters of DCF | Parameter Value |
|-------------------|-----------------|
| Length            | 10 km           |
| Attenuation       | 0.5 dB/km       |
| Dispersion        | -85 ps/nm/km    |
| Dispersion slope  | -0.3 ps/nm2/k   |
| Group Velocity Dispersion | Yes         |
| Third-Order Dispersion | Yes         |

C. Receiver part

For the receiver part, it consists of a DeMmultiplexer of 1*32 for optical signal recombining, a photodetector with a type of PIN to handle the function of converting the optical signal back into an electrical signal, Low Pass Bessel Filter (LPBF) with a cut-off frequency of 0.80*bit rate value, 3R generator and finally the BER analyzer as seen in Figure 8. It is worth to mention, that the utilization of LPBF was to separate the individual's RF signal from each other. In addition, it is used to control the nonlinear effects of crosstalk and hence would improve the system's overall performance. The performance of our proposed DWDM-RoF system would be investigated through the BER analyzer tool by considering the parameters of Q-factor, Min BER, and eye diagram as clarifying in the next section.

Figure 8. The receiver part of our DWDM-RoF system

5. Results and Discussion

The performance analysis of the proposed scheme would be for nine selected channels of 1, 4, 8, 12, 16, 20, 24, 28 and 32 and based on the parameters of optical spectrum, eye diagram, Q-factor and Min BER. The optical spectrum for the multiplexed signals has been analyzed by using the dedicated Optisystem tools, The spectrum analyzing has been performed within two locations, the first was after multiplexing the 32 channel and secondly after the transmission of the 60, 120 and 180 km as seen in Figure 9. In order to get a closer look at the impact of noise between the multiplexed signals after and before
transmission. The eye diagram parameter, which could indicate the quality of the signal received, has been analyzed as seen in Figure 10, 11 and 12 and for 60, 120 and 180 km respectively. It can notice a clear eye for lower distances (60) km indicating the higher quality of the signal received for these selected channels. While increasing in distances will raise the impact of BER and reduce the Q-factor. Hence, the utilization of DCF could be noticed clearly in this case, which would boost the signal and reduce the effects of chromatic dispersion.

Figure 9. The analyzed optical spectrum for (a) after 32*1 Mux, (b) after 60 km transmission, (c) after 120 km transmission and (d) after 180 km transmission
Figure 10. Eye diagram of our DWDM-RoF system for distance of 60 km
Figure 11. Eye diagram of the proposed DWDM-RoF system for distance of 120 km
Figure 12. Eye diagram of our DWDM-RoF system for distance of 180 km
Furthermore, the utilized wavelength selected for each channel are listed in table 3. The measurement of Max Q-factor were obtained for the sampled selected channels. These results were 25.44, 14.84, 15.07, 14.47, 14.99, 16.65, 15.29, 15.66 and 14.25 respectively with the case of 60 km distance. Q-factor results indicate a higher performance of 1.28 Tbps DMWD based RoF system.

Table 3. The wavelength utilized per each channel in our DWDM based RoF system

| Channel Number | Wavelength | Channel Number | Wavelength |
|----------------|------------|----------------|------------|
| Ch1            | 190        | Ch17           | 193.2      |
| Ch2            | 190.2      | Ch18           | 193.4      |
| Ch3            | 190.4      | Ch19           | 193.6      |
| Ch4            | 190.6      | Ch20           | 193.8      |
| Ch5            | 190.8      | Ch21           | 194        |
| Ch6            | 191        | Ch22           | 194.2      |
| Ch7            | 191.2      | Ch23           | 194.4      |
| Ch8            | 191.4      | Ch24           | 194.6      |
| Ch9            | 191.6      | Ch25           | 194.8      |
| Ch10           | 191.8      | Ch26           | 195        |
| Ch11           | 192        | Ch27           | 195.2      |
| Ch12           | 192.2      | Ch28           | 195.4      |
| Ch13           | 192.4      | Ch29           | 195.6      |
| Ch14           | 192.6      | Ch30           | 195.8      |
| Ch15           | 192.8      | Ch31           | 196        |
| Ch16           | 193        | Ch32           | 196.2      |

Moreover, the proposed system would be tested and analyzed for longer distances reaches 180 km and this is performed by clarifying the relation between the BER values vs. the distance of 60, 120, and 180 km as seen in figure 13. It can be concluded from the overall trends a direct correlation between them where increasing the distance would raise the effects of crosstalk and hence increase the BER value. In addition to that, the relation between the Q-factor and distance was investigated and analyzed as seen in figure 14, where a reverse relation was found between them as increasing the distance would reduce the quality of the received signal.
6. Conclusion
In this paper, it has been proposed a scheme for DWDM-RoF system to support higher data rates towards the Tera bit data transmission for 5G based communication networks. The proposed system was based on the utilization of 32 channel X 40 Gbps, and could achieve a bit rate of 1.28 Tbps. The investigation for the system performance would consider different distances of 60, 120 and 180 km. The parameters of eye diagram, Q-factor and Min BER would be considered and obtained for the performance analyses of our schemes and by using the software of Optisystem 17.1. The results of eye diagram showed higher quality indication for the received signal per different distances. Analyzing result indicate a direct relation that has been found between distance and the Min BER as increasing the transmission distance would raise the value of error within the transmitted bits. Meanwhile, Q-factor has shown a revere impact with increasing the distance, which would reduce the impact of the transmitted signal quality. The utilization of both EDFA along with DCF is for optimizing the proposed system and reducing the impacts of dispersion compensation effects. As a result, the proposed system showed a higher reliability and adaptability for our proposed DWDM-RoF systems and confirm the fact that WDM could be considered as the best method to be utilized in RoF system.

7. References
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