Investigating the Performance of Wavelength Division Multiplexing based RoF Optical Network with Dispersion Compensation Fiber

Raghad Z.Yousif¹, Nahlah Qader Mohammed², Amanj Fransis³

1- Department of physics-Communication, College of Science, Salahaddin University, Erbil, Kurdistan Region, Iraq.
2- Department of Physics, College of Education, Salahaddin University -Erbil, Erbil, Kurdistan Region, Iraq.
3- Department of physics, College of Science, Salahaddin University, Erbil, Kurdistan Region, Iraq.

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*Corresponding Author:
Raghad Z.Yousif
Raghad.yousif@su.edu.krd

ABSTRACT

A Radio-over-Fiber (RoF) make use of the advantages of wireless communication system and optical networks. It uses optical fiber as a core technology due to the enormous advantages offered by it. Making use of mobility available by wireless communication. Dispersion management and modulation were investigated for two Channel-WDM optical communication systems. Dispersion compensating fibers (DCF) are used to compensate the positive dispersion accumulated over a protracted haul SMF between CS (central Site) and BS (Base Station). The full duplex RoF system is implemented by means of Wavelength Division Multiplexing (WDM) and Optical Add Drop Multiplexer (OADM), where WDM enables transmission of many signals via a single mode fiber for long distance while OADM allows data transmission of both down-link and uplink a by single-mode fiber (SMF). The modulation technique employed by the proposed system is DPSK. which has some advantages over binary PSK, like a low phase error rate and no need to know the absolute phase. The proposed RoF system has been simulated using Opti System 13.0 simulator. The system outcomes like the Q-factor, and BER with and without (DCF) at different fiber length have been used to discuss system performance. It has been observed that the proposed system improves the Q-factor by 6-units and the BER by 24 dB at CS and 57dB at BS respectively.

1. INTRODUCTION

Due to increased demand on high data capacity of wireless communication systems which is extremely expanded from voices and simple messages to multimedia in order to satisfy various demands of system users with evolutionary future services. The fundamental reason of Radio over Fiber (RoF) technology is to improve the usage of spectrum resources and reduce the cost of far off BS modules (Turan Erdogan et al., 1997) (W.W.Hu et al., 2004). RoF systems is a promising technique might urgently handle the huge demands of the telecommunication networks, as they could provide the sufficient bandwidth for the transmission of broadband data to end-users, other benefits are low attenuation loss, and immunity to radio frequency interference (H. Nasoha et al., 2007)(Hyun-Seung Kim et al., 2009)(A Nirmalathas, et al., 2010)(Y. M. Lin et al., 2010). The advantages of communication system based on RoF
technology is the exquisite development space in the 3G and 4G (Turan Erdogan et al., 1997) (W.W.Hu et al., 2004). Current tendencies in cellular networks are: reduction in cell size to serve more users and Operation in microwave/millimeter wave (mm-wave) frequency bands to avoid spectral congestion in lower frequency bands. It demands a large number of Base Stations (BSs) make full coverage for the served area, thus it’s important to reduce the cost of BS. This requirement has caused the improvement of system architecture where functions such as signal routing/processing, handover and frequency allocation are carried out at a (CS), in preference to on BS. Furthermore, such a centralized configuration permits sensitive devices to be located in safer and secure and enables the cost of costly components to be shared among several BSs. A RoF system includes (CS) and a Remote Site (RS) connected to an optical fiber link or network. The signal between CS and BS is transmitted in the optical band via RoF network. This architecture layout makes the design of BSs quite simple. In the simplest case, the BS includes particularly optical-to-electrical (O/E) and electrical-to-optical (E/O) converters, an antenna and some microwave circuitry (two amplifiers and a diplexer). In the event of ability region is in a GSM network, and then CS might be the Mobile Switching Centre (MSC) and RS the base station (BS). As for narrowband communication systems and wireless Local Area Networks (WLANs), the CS will be the head-end while the Radio Access Point (RAP) would act as the RS. RoF systems span a wide range (usually in the GHz region) and based on the nature of the applications to distribute the frequencies of the radio signals. Besides transportation and mobility features, RoF systems are also designed to carry out added radio-system functionalities. These functions include data modulation, signal processing, and frequency conversion (up and down) (Peng, et al., 2009)(Keiser, G 2011). As depicted in Figure 1, RoF systems were in the whole used to transport microwave signals and to reap mobility functions in the CS. The centralization of RF signal processing functions has many advantages such as permitting devices sharing, dynamic allocation of resources, and simplifies system operation and maintenance. These benefits might be translated into major system installation and operational savings, especially in wide-coverage broadband wireless communication systems, in which a high density is necessary.

![Figure (1) : The structure of Radio over fiber system](image)

With the non-stopped development of studies on RoF, in optical communication, (WDM) technology has been very mature. WDM support high bandwidth data transfer, it is able to simplify the network structure that multiplexing a multi-channel RoF signals and transmitting in on a single fiber. The integration between RoF and WDM is abbreviated as WDM-RoF system (Turan Erdogan et al., 1997) (W.W.Hu et al., 2004). The management of dispersion and non-linearity's are most important issue in WDM systems (A. Mohan 2014), the dominant goal of optical fiber communication system is to increase the transmission distance (Y. Chaba et al., 2010). The principles factors which impact the WDM system are loss, dispersion, and non-linear effects. In order to reduce the impairments due to fiber non-linearity's optical
amplifiers such as Erbium Doped Fiber Amplifier (EDFA) (Simranjit Singh et al., 2014) has been used. The use of DCF is a powerful way to reduce the complete dispersion in WDM network as they have higher negative dispersion coefficient and can be attached to the transmission fiber having positive dispersion coefficient so that the complete dispersion of the link becomes zero. (Gurinder Singh et al., 2014). The (Differential Phase Shift Keying) DPSK is a quick and stable modulation format and perfectly fits many optical applications. It has some advantages to the binary PSK, like a lower phase error rate and a no need to know the absolute phase. In this paper, Q-factor and BER of 2 channel WDM systems are analyzed over a distance less than 108km for channel from CS to BS with and without DCF of 10km.

2. RELATED WORK

Husam Abduldaem Mohammed (Husam Abduldaem Mohammed 2013) investigated the overall performance of DWDM system utilizing EDFA and DCF for different lengths of optical fiber and bitrates. He found that the most effective factors causing performance degradation are attenuation and dispersion. EDFA is used in the system model to combat the effects of attenuation and scattering losses, while DCF is utilized to mitigate the effects of dispersion. Bo-ning Hu, Wang Jing, Wang Wai, Ruimei Zhao (Bo-ning Hu et al., 2010) analyzed the fiber optic dispersion and its effects on optical transmission system. Most frequently used dispersion compensation fiber technology. Three schemes of dispersion compensation with DCF are implemented using OptiSystem and various results such as Q factor and BER are analyzed. X.Y.Zou, M.Imran Hayee, S-M Hwang and Alan E.Willner (Gerd Keiser et al., 2000) analyzed the system limitations of WDM transmission when using various types of optical fiber to control dispersion and nonlinearity. In the system 2 to 8 10gbps WDM channels are transmitted through a cascade of EDFA’s experiencing dispersion, stimulated Raman scattering. Sandeep Singh (Sandeep Singh., 2012) studied dispersion compensation system in the WDM in this paper. Based on optical transmission equation, considering the various types of nonlinear effects and the effect of EDFA, system simulation models are constructed.

3. MATERIALS AND METHODS

This section will describe the main optical and electrical components used in the RoF proposed system implementation, with proposed system diagram.

3.1 Dispersion Compensating Fiber (DCF)

The concept behind this compensation approach is to make Single Mode Fibers (SMF) followed or preceded by DCFs with negative dispersion coefficient, with purpose to disable the effect of positive dispersion of SMFs. The dispersion compensating fiber for dispersion compensation was proposed in 1980’s. The components of DCF are not easily influenced by temperature and bandwidth, due to the fact that DCF is more stable. DCF in an efficient way to mitigate the overall dispersion in WDM network, because of its higher negative dispersion coefficient therefore, it can be connected to the transmission fiber having the positive dispersion coefficient such that the overall dispersion of the link is zero

\[ D_{\text{smf}} \times L_{\text{smf}} = -(D_{\text{DCF}} \times L_{\text{DCF}}) \]

(1)

Where: D and L are the dispersion and length respectively. As a result, among various dispersion, compensating schemes, DCF having high negative dispersion at 1550nm is widely inserted at regular intervals along the optical fiber link (Bryn J. Dixon et al., 2001). In order to realize the high data speed communication system, a specific DCF
having large negative dispersion for cancelling the dispersion of a transmission channel is currently installed in a repeater or a transceiver.

3.2 Wavelength Division Multiplexing (WDM)

The technique which allows the optical fiber to carry multiple signals is called wavelength division multiplexing. It is a technique used in sending signals of several different wavelengths of Light into the fiber concurrently. In fiber optic communications (WDM) is a technology which multiplexes multiple optical carrier signals on a single optical fiber by using different wavelengths of Laser light to carry different signals. This facilitates the improvement of system capacity and also allows bi-directional transmission over single fiber length for transmitter and receiver. The basic operation of WDM is the combination of multiple optical channels with different wavelengths, received from different optical sources into a single fiber using multiplexers at the transmitter end, and de-multiplexer in the receiver to split WDM channels (Biswanath Mukherjee 2006). The capacity of the Radio-over-Fiber (RoF) systems can be increased by applying (WDM) technology in the optical fiber. It is an effective way to increase the usable bandwidth of the fiber (Masuduzzaman Bakaul 2006).

3.3 Differential Phase Shift Keying (DPSK)

An alternative to the BPSK can then be the differential phase shift keying (DPSK) method. The difference between the binary and the differential PSK is that in the DPSK the bits are represented by a change of phase. When a binary one is sent the phase is unchanged from the previous bit, and a binary zero is represented by a change of the phase (W. Stallings 2001). As shown in figure (3).

\[
\begin{array}{cccccccc}
0 & 1 & 1 & 0 & 1 & 0 & 1 & 1 & 1 & 0 & 1 & 0
\end{array}
\]

Figure (3) Differential Phase Shift Keying example

The DPSK technic has some advantages as compared to PSK. Since the information is stored in the phase change and not in the phase itself it is miles good for systems where the accurate phase is not known (M. Sundelin. 1995). For that reason, if the system is affected by phase noise, the detection of the signal is made easier with DPSK. But at the same time, you lose about 3 dB of power by using DPSK instead of PSK because of the receiving technique.

3.4 Optical Add-Drop Multiplexing (OADM)

Optical add-drop multiplexer (OADM) is a device used in wavelength division multiplexing systems for multiplexing and routing different channels of light (Sandeep
Singh et al., 2012). Add and drop here refer to the capability of the device to add one or more new wavelength channels to an existing multi-wavelength WDM signal, and to drop one or more channels, passing those signals to another network path. An OADM may be considered to be specific type of optical cross connect. A traditional OADM consists of an optical de-multiplexer, an optical multiplexer, and between them a method of reconfiguring the paths between de-multiplexer, multiplexer and a set of ports for adding and dropping signals. Physically, there are several ways to realize an OADM. In proposed design, the base station (BS) has been implemented using OADM.

3.5 Proposed System Design

Simulation layout of proposed RoF system to mitigate dispersion is shown in Figure 4. The PRBS represents the information or data that is to be transmitted. From the pseudo-random bit sequence generator which generates electrical signal with data rate of 5 Gbps. Then the data signal is introduced to a DPSK modulator with 1 bit/symbol, which has a carrier of frequency 5 GHz. The DPSK modulated electrical signal is filtered by a low pass Bessel filter, Bessel LPF is used with cut-off frequency of 1.5 x bit rate of the signal. The two channels RF electrically modulated signals then introduced to two Mach-Zehnder modulators with optical carriers of frequencies 193.1 THz and 193.2 THz (the frequency spacing between the channels is 10 GHz) emitted by two CW lasers of 0.1 dBm power. The modulated optical carriers from two (CS) channels are multiplexed by (2 x1) WDM multiplexer up to (BS). Many wavelengths of light from different transmitters are combined together by the WDM multiplexer. Then the output of the MUX is fed to a single mode fiber (SMF) via a booster. The (SMF) used has a dispersion of 17 ps/nm/km, with dispersion slope of 0.075 ps/nm²/km, effective area of 80µm², nonlinearity coefficient of 2.6*10⁻²⁰, PMC Coefficients of 0.2 ps/km and a loss of 0.2 dB/km. After a length of 50km in the direction of BS the multiplexed optical signal is fed to the EDFA with a gain of 10dB which is used in the proposed system to compensate for the attenuation losses. Multiplexed optical channel consists of 50 km of SMF and 10 km of DCF. The most fundamental reason that
limits the transmission of high-speed signals on the 1550nm optical fiber is the linear dispersion, the dispersion of SMF is 17 ps/nm/km, and therefore the DCF might be used for compensating their dispersion performance. DCF’s chromatic dispersion is negative (dispersion coefficient is \(-85\) ps/nm/km), DCF’s dispersion slope of \(-0.3\) ps/nm\(^2\)/km, effective area of \(30\mu m^2\), nonlinearity coefficient of \(2.6*10^{-20}\), PMC Coefficients of 0.2 ps/km and a loss of 0.4 dB/km. Its dispersion characteristics are coinciding contrary with the SMF’s, if the length of DCF is the SMF’s \(1/5\), then the total transmission line dispersion value close to zero. But, the DCF attenuation is larger, to solve this problem, EDFA was brought to compensate linear loss after the DCF and near to the BS. At the BS, OADM is employed such that a signal with frequency 193.1 THz is simultaneously added and dropped as uplink and downlink data respectively. The dropped signal is first passed through an optical Bessel filter of frequency 193.1 THz and bandwidth 10 GHz, then the signal is detected using a PIN detector, filtered using a low pass Bessel filter and fed to a BER analyzer for the analysis of Q factor and BER of downlink. The multiplexed signal having frequency 193.2 THz along with uplink data of 193.1 THz, added from BS, is transmitted to CS via SMF of attenuation 0.2 dB/Km and length of 50km before introduce it to the EDFA and DCF of 10km before feed the optical signal to destination CS. At CS, the signal is de-multiplexed; the role of optical receiver is to convert the optical signal into electrical form. Thus, the optical signal optically filtered using an optical Bessel filter and detected using a PIN detector of responsivity 1 A/W and dark current of 10 nA. The recovered electrical signal is filtered using a low pass Bessel filter with cut-off frequency of 0.75*symbol rate and given to a BER analyzer for the analysis of uplink data. To analyze the performance of RoF system with different SMF the 50km fiber is replaced by different distances from (12-108) km.

4. RESULTS AND DISCUSSION

The performance of DPSK modulated WDM RoF system with and without DCF and EDFA is investigated in terms of the Q-factor, Bit Error Rate (BER). The bit rates are considered constant and equal to 5 Gb/s. The measurement component used is BER analyzer to measure Q-factor & BER. The spectral power spectrum with respect of frequency at the output of the WDM in the Central site is depicted in figure (5). While the power spectrum at the output of the Base station OADM is depicted in figure (6). The chromatic dispersion which results in signal broadening over large bandwidth in an optical signal transmitted form CS to BS has been mitigated by using DCF. The EDFA of a gain of 10dB has been added before the DCF to compensate for the SMF linear losses.

Figure (5) Optical spectrum of the WDM signal at CS (channel spacing 10GHz).

The impact of the changing the SMF length (the fiber length is changed form 12-108 km) on system performance is studied with and without (DCF-EDFA)
components in the optical channel, between CS and BS. Figure (7) shows a graph of Q-factor in the CS and BS without (DCF-EDFA) components. Basically, the Q-factor is decreased with fiber length increase. But this degradation in Q-factor is mitigated by using (DCF-EDFA) components in the channel, which is illustrated by Figure (8).

As an example, at fiber length of 50km the Q-factor at CS is about 9 while it's equal to 12 at BS without using (DCF-EDFA) components. But when using (DCF-EDFA) components the optical signal is restored and hence the Q-factor is enhanced to 14.5 at CS and 18 at BS with calculated gain about 6. Figure (9) and figure (10) depicts the effect of (DCF-EDFA) components in improving the proposed RoF system BER.
better than BER at CS, but at a distance of more than 70 km the BER is comparable between CS and BS in case without (DCF-EDFA) components, while this distance is increased to about 95 km with (DCF-EDFA) components.

Figure (10) BER vs. optical fiber length with (DCF-EDFA)

proposed diagram. It’s clear that after 0.5 sec time period there would be a real degradation in the proposed system performance due the increase in transmitted signal; dispersion which increased with increased transmitted signal duration. Again, if we take as an example a fiber length of 50 km the log (BER) is -18 dB, and -33 dB at the CS and the BS respectively with (DCF-EDFA) components while in other case these values become (-42 dB) at CS and -90 dB at BS providing a BER gain of 24 dB at CS and 57 dB at BS respectively. The BER is further improved if the length of fiber decreased, it could reach -320 dB at fiber length of about 22 km.

Figure (11) a,b,c gives graphical illustration for the BER with respect to the Q-factor as indicated by the

Figure (11): (a,b,c): BER and Q-Factor vs. bit period with (DCF-EDFA)
5. CONCLUSIONS

The performance investigated through OptiSystem13, 2-channels WDM RoF communication system using DPSK modulation with optical channel based on EDFA and DCF is designed and presented. Here externally modulated transmitter is used to achieve stability and reduced non-linear effects. The EDFA with dispersion compensation technique provides better Q-factor and minimum BER in both CS and BS. The results obtained indicated that the Q-factor is very much enhanced by the proposed system while BER is very much reduced. After using dispersion compensation, the signal is restored hence the Q-factor is increased.

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