January-February 2020
ISSN: 0193-4120 Page No. 11714 - 11727

A Comprehensive Survey on OFDM Based Radio over Fiber Modulation System

Nitika Sharma, Electronics and Communication Engineering, Chandigarh University, Punjab 140413, INDIA
Arpan Garg, Electronics and Communication Engineering, Chandigarh University, Punjab 140413, INDIA
Nitin Mittal, Electronics and Communication Engineering, Chandigarh University, Punjab 140413, INDIA

Article Info
Volume 82
Page Number: 11714 - 11727
Publication Issue:
January-February 2020

Article History
***Article Received**: 18 May 2019*
***Revised**: 14 July 2019*
***Accepted**: 22 December 2019*
***Publication**: 21 February 2020*

Abstract:
As a modulation system, Orthogonal Frequency Division Multiplexing (OFDM) transmits both wireless and optical channels and can spread the data across a large number of subcarriers. This received RF signals for long-haul transmission using the RoF system. The wireless network is considered the RoF (Radio over Fiber) system to improve the OFDM modulation signal's high orthogonality. It used both fixed and mobile networks for the next decade. For high data transmission, OFDM for mobile and RoF can be used for short distance or long backhaul networks. This begins with the implementation of fiber optics and then goes on with its transmission features to the concept of fiber optic cable. The concept of radio over fiber (RoF) is also discussed briefly. This research investigates the feasibility of multiplexing orthogonal frequency division (OFDM) as a RoF modulation system. OFDM fundamentals are then described, including its basic mathematical formulation. Among the modulation techniques, OFDM has achieved a fair level of eminence. Also presented is the generation and reception of RF-OFDM signal together with its optical device signal processing. In addition, OFDM's merits and demerits were advised on the basis of this technique's acceptance and popularity. In the next section the literature survey will be updated on the problem being formulated and the goals mentioned will be achieved.
Keywords: *Optical Fiber Communication; Orthogonal Frequency Division Multiplexing (OFDM); Radio over Fiber (RoF); Optisystem*

INTRODUCTION

In the era of information technology i.e. the 21st century, there is an ever-increasing demand for high data rate and longer transmission. With the increase in demand for personal communication and internet-based services such as video conferencing, video on demand (VoD), high speed is required for transmission in order to prevent congestion in the network. To fulfill the necessity of high data rate, fiber optics is considered as an appropriate technique. Fiber optics is a technology in which information is transmitted in the form of light by using "waveguides". A general optical system comprises of a transmitter, that generates the light signal e.g. laser or LED (light emitting diode); an optical fiber, that carries the light using total internal reflection; and a receiver, that converts the light signal into electrical signal e.g. photodiode. It has revolutionized the entire communication system, the way we transmit and receive information, and has played a wide role in ushering in the information age. It creates inquisitiveness among the scientists to make advances in communication. Research in optical communication has received a lot of interest in recent years. It presents many advantages over conventional copper transmission such as low attenuation, high capacity, interference immunity, good electrical isolation and wide bandwidth. Due to this, the optical fiber dominates the copper wire in industry. Nowadays, these are also used in internet as well as local area networks to attain high signaling rates along with its use for telecommunication.

Since ancient times various communication systems were getting interest among which optical communication system is one getting special interest. The use of light to transmit messages is not new. In the eighth century BC Greeks used fire signal for sending alarms was a common example of optical transmission link. But these systems did not get attention at that time due to technological limitations. Afterwards, no developments in optical communications were seen till the end of the 18th century. The use of glass fiber to carry an optical signal originated in late 19th century (1880) with the invention of light

communicating device known as photo phone by Alexander Graham Bell [1]. A way must be found to correctly guide the light to the atmosphere. Further progress in light communication came around 1960's; with the invention of the laser but due to the attenuation problem it was not that suitable for optical communication [2]. The lack of optical media prevented it from working effectively due to the enormous losses. The researchers find a way to avoid interference from outside by guiding the laser's light into a cable. But there exists a problem of travelling the light in a cable which led to the invention of glass medium for optical fiber cable in 1966 by Charles K. Kao but with an attenuation of 1000 dB/km which was also not much practical [3]. In 1970 low attenuation (around 20dB/km) optical fiber was developed by Corning Glass Works which was suitable for communication purposes and for long distance transmission [4]. Further improvements in the fiber and laser technology LED the use of fiber optics in telecommunication industry and become a good replacement for the copper cables [5-10].

1. Optical Communication System

Fiber optic communication is getting a lot of interest in telecommunications as it can provide high bitrates as well as long distance transmission [4]. It is the technique in which light is used for information transfer between two different places. It uses waveguides in the form of optical fiber to guide the light or the optical signal through total internal reflection and serves the purpose of transmission medium [6]. An optical fiber fabricated from glass (silicon dioxide) are typically more common for long distance transmission but for low cost systems plastic (polystyrene or polymethyl methacrylate) fibers can also be used. It consists of a central core of high refractive index surrounding by a cladding made from a material of slightly lower refractive index. This difference in indices is required for total internal reflection (TIR) [7-10]. Cladding serves the purpose of retaining the light within the core and to provide the mechanical strength. The general optical fiber communication system as shown in **Figure 1** consists of optical transmitter, which generate the optical signal; optical fiber, which relays the signal from transmitter to receiver, and ensuring proper amplitude and shape of the signal; optical receiver, which converts the signal back into electrical form.

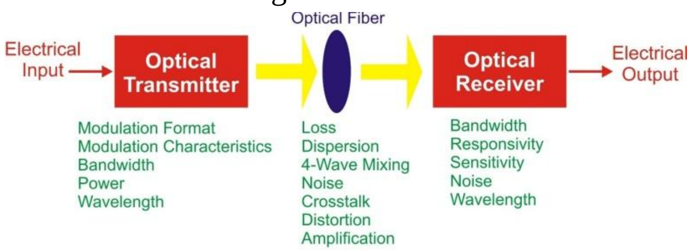

Figure 1. General Optical Communication System

Figure 2 enlightens the light wave system components including transmitter and receiver sections. An optical fiber transmission begins with a light source and ends with a photo detector. The transmitter section consists of an optical source such as LED or laser diode which produces the light signal. The light is directed into an optical modulator along with an electrical signal. Information can be imposed on the laser light by modulating the laser

January-February 2020
ISSN: 0193-4120 Page No. 11714 - 11727

itself with the electrical signal or externally using electro-absorption or electro-optical modulators. For higher data rates, external modulation is more preferable because direct modulation widens the laser linewidth and produces a chirp. The signals arriving at the receiver are converted back into the electrical signals by photo detector. Positive-intrinsically-negative (PIN) photodiode and avalanche photodiode (APD) are the two most popular photo detectors. The key parameters behind photo detectors ' decision are quantity performance, responsiveness, sensitivity and response speed [10]. APD is more flexible, but more costly than PIN.

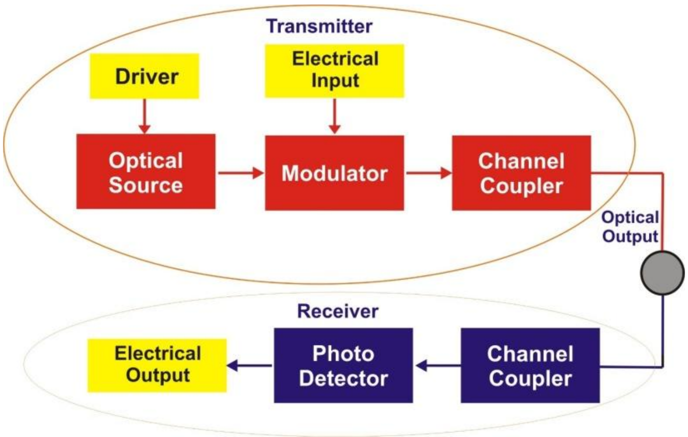

Figure 2. Lightwave System Components

1.1.Principle of Ray Propagation in Optical Fiber

A very basic process of complete internal reflection (TIR) [11] guides the light beam through the optical fiber. As shown in **Figure 3**, this is called the theory of ray propagation. This happens due to differences in core and cladding refractive indices and the core refractive index should be lower than cladding in order to contain the light in the core. The light ray travelling in the core refracts into the cladding depending on the angle at which strikes the core material. At a certain angle when incident angle becomes greater than critical angle, θc (the incidence angle at which angle of refraction is 90º), it reflects back into the core completely. This is called total internal reflection (TIR) [11]. The light has to penetrate the fiber within an imaginary approval cone (2a) to ensure the TIR. The angle of acceptance (a) is the highest angle to allow the light into the fiber. The light ray entering the fiber within the acceptance cone can only be guided or restricted in an optical fiber and therefore the angle should be chosen carefully.

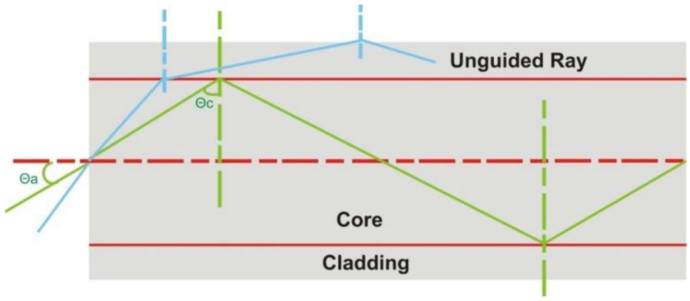

Figure 3. Principle of Ray Propagation

1.1.Geometrics of Optical Fiber

As shown in **Figure 4**, optical fiber is a mixture of cylindrical core and cladding greater than cladding with core refractive index. These are referred to as – phase index and graded index fibers, depending on the fibers refractive index profile. The fibers in which the core refractive index is constant, and the step-index fibers are considered a sudden shift in the refractive index at the core-cladding interface. While the fibers are known as graded index fibers, where the refractive index is not constant but gradually decreases within the center as a function of the radial length. There may be two types of phase index fibers: single and multi-mode fibers[12-13].

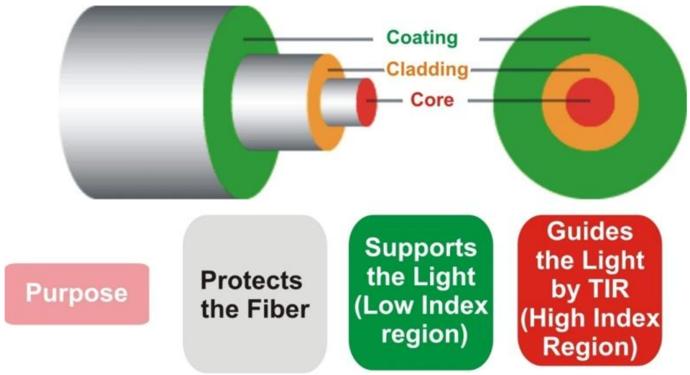

Figure 4. Structure of Optical Fiber

1.1.Transmission Impairments in Fiber

January-February 2020
ISSN: 0193-4120 Page No. 11714 - 11727

Attenuation and dispersion are the two most significant impairments in the fiber. These will affect the performance of entire communication system. Out of the three transmission windows, 1310 nm and 1550 nm windows are usually common. A standard single-mode fiber exhibit minimum dispersion at 1310 nm and at 1550 nm it has minimum attenuation. 1550 nm wavelength band is more common along with dispersion shifted fibers [14].

1.1.1. Attenuation

The decrease in signal strength or loss of the optical power as it propagates along the fiber is known as attenuation and is expressed in dB/km. The various mechanisms are responsible for the attenuation of the signal such as material absorption, linear and non-linear scattering etc.

Material Absorption. Pure silica glasses usually do not cause absorption but causes a little absorption called as intrinsic absorption in the near-infrared region due to the interaction of the light with one or more of the major components of the silica. It is also caused due to the impurities present in the glass such as hydroxyl (OH$^-$) ion or metallic ions (Cu_2^+, Fe_3^+) known as extrinsic absorption.

Linear Scattering Losses. Most of the attenuation is caused due to the scattering losses. This mechanism results in the attenuation as it transfers a part/total optical power travelling in one propagating mode to another keeping frequency unaltered i.e. linearly and the transferred mode can be leaky or radiation mode. It is of two type's viz. Mie scattering and Rayleigh scattering. Structural imperfections, irregularities in the core-cladding interface and bubbles may cause scattering known as Mie scattering occurring because of the inhomogeneity's greater than optical wavelength. Rayleigh scattering occurs when the density and compositions of the core results in producing fluctuations in refractive index. It can be reduced to a large extent by improved fabrication and by using longest possible wavelength but cannot be avoided.

Non-Linear Scattering Losses. Due to the non-linear behavior, scattering at high optical powers causes attenuation. It transfers the optical power from one propagating mode to the same or different mode but with a change in the frequency. This can scatter light in forward or backward direction. These effects usually cause an increase in optical gain but with an optical frequency shift. The non-linear scattering is categorized as stimulated Brillion scattering (SBS) and stimulated Raman scattering (SRS). Scattering of light in the backward direction as a result of the interaction with acoustic (sound) waves arising due to the mechanical vibrations in the fiber is known as SBS. It becomes a stimulated process when input power exceeds a threshold level. Whereas, scattering of light from high frequency optical phonons is known as SRS. The energy transfer occurs between the optical wave and optical photons because of their interactions due to the molecular vibrations rather than mechanical ones. Nonlinear effects are dependent on intensity and therefore at high optical power they can become very significant.

1.1.2. Dispersion

Signal dispersion tends to limit the overall bandwidth of the fiber. The bandwidth determines the total number of bits transmitted in a particular time interval. It leads to the spreading of the light pulses or blurring of signal as they propagate inside the fiber, degrading the signals usually over long distances. As an example; dispersion is seen in a rainbow, in which white light is spatially separated into different color wavelengths due to dispersion effect. It is a major problem in digital transmission. By selecting the bit rate lesser than the inverse of broadened pulse duration, it can be avoided.

Intermodal (Modal) Dispersion. In a multimode fiber, different modes of a single frequency follow different paths and reach the other end at different times. The rays that touch the cladding will reach later than the rays that travel straight along the axis of the core. Therefore, the core's refractive index profile is responsible for intermodal dispersion and therefore leads to pulse expansion. In addition, the main problem is generated by the different group speeds with which the modes pass through the fiber. This is not seen in fibers of single type. The graded index profile removes the multimode fiber modal dispersion. Therefore, it produces a major problem in the multimode phase index fibers. With an increase in length, this form of dispersion increases.

Intra-Modal (Chromatic) Dispersion. It occurs due to a finite spectral width of the optical sources in almost every optical fiber. The optical sources are designed to emit a band of frequencies rather than a single frequency. These bands of frequencies can propagate at different velocities. When the propagation at different velocities occurs due to the dependence of the refractive index of the material (silica) on wavelength, it is called material dispersion or spectral dispersion (as this phenomenon is similar to the spreading of a spectrum after passing through prism). But on the other hand, waveguide dispersion is caused due to the imperfect guidance effect of the
waveguide. As in single mode fiber some of the light can propagate through cladding which causes the light to travel at increased speed than that of the light propagating through the core and thus causing the propagation delay. It is almost negligible in multimode fibers as the penetration of light into cladding is very less in this.

Polarization Mode Dispersion (PMD). Polarization mode dispersion is also a type of broadening of pulse and occurs due to fiber birefringence (fiber asymmetry). Within a single mode, two orthogonally polarized modes can propagate which can travel at the same speed in ideal fibers. Whereas in practice, fibers may have some asymmetries like fiber defects and bends which leads to birefringence. This causes the splitting of the polarized components and results in pulse spreading because these components propagate at different velocities.

2. Radio Over Fiber (RoF) Technologies

Radio-over-fiber (RoF) is a technique in which the radio frequency (RF) signal is based on a light signal before being transmitted over the fiber and is recovered back to the RF signal at the receiving end through demodulation and relayed to the correct wireless user. To transmit the RF signals over fiber, optical modules and techniques are used. Depending on the frequency range of the radio signal to be transmitted it can be categorized into two types– radio frequency (RF) over fiber and intermediate frequency (IF) over fiber. RoF techniques are supposed to bridge the gap between the large capacity of optical fibers and the flexibility and mobility of wireless transmission. It is the interconnection of wireless (RF) and optical domain. It provides wireless access along with the advantage of low attenuation and wider bandwidth of optical fibers without much cost increment. Also, it provides low complexity with lower cost due to a simpler structure that has made it popular among various communication systems. It is one of the recent technologies in fiber optics. Over the past two decades, it has become a popular invention and has gained the attraction of competent researchers to satisfy the ever-increasing demand for high data rate and mobility [16].

A general RoF system consists of a radio frequency (RF) signal, optical system hardware to modulate a light with an RF signal and to recover RF signal form optical signal, and an optical media. Central station (CS), base station (BS) and fiber are three major constituents of RoF system architecture as shown in **Figure 5.**

TEST Engineering & Management

January-February 2020
ISSN: 0193-4120 Page No. 11714 - 11727

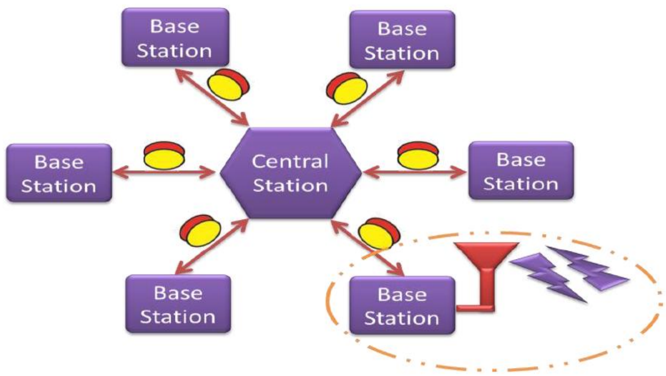

Figure 5. RoF System Architecture

Radio signals are transported between CS and several BS's via fiber before and after being radiated through the air in downstream and upstream transmissions respectively. Each BS will have a radio connection with at least one mobile user situated within the range of BS. Radio signal transmission between CS and BS in RoF system is shown in **Figure 6**. In the downlink direction, central station requires a modulated RF signal to modulate the optical source and uses the fiber to transmit this optical signal to BSs. At the base station, optical receiver such as photodiode is used to convert it into RF again and is directed to the user terminal (mobile terminal). Likewise, in the uplink transmission, RF signal received from the mobile unit through wireless channels reached the base station, where it is demodulated depending upon the frequency range of radio signal and base station configuration. It is transformed to optical signal by modulating an optical source located in BS with RF signal to transmit the information back to the CS by launching it into the fiber. Photo detection of the signal is then done in CS. The use of simple and cost-effective BS is considered to be one of an important factors in RoF technology.

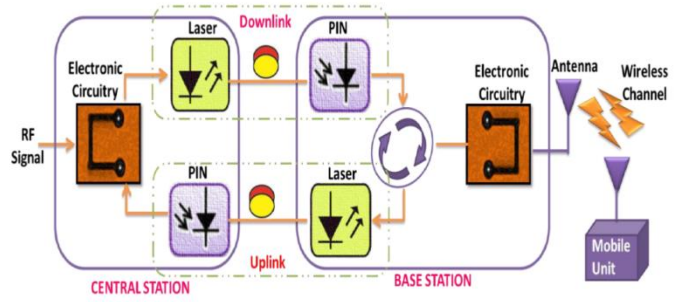

Figure 6. Radio Signal Transmission between CS and BS in RoF System

In wireless systems, the signals fading occurs during the transmission mainly due to the atmospheric conditions, thus the radio over fiber system is widely used to overcome these issues. Radio over fiber (RoF) system solves a lot of issues of the wireless system such as transmitting high frequency signals in the form of light signals will make these systems immune to radio frequency interference, using low loss fibers will make it cause less attenuation whereas to transmit high frequency signals with low attenuation requires expensive circuitry, large bandwidth is offered by fibers etc. Thus, RoF technology provides low cost equipment's and wireless excess in the optical communication system. For OFDM signal to transmit using radio over fiber (RoF) technology, the data meant for a particular end user is generated in a central station, where RF signal is imposed on a number of lower rate orthogonal subcarriers and transmitted over the fiber after being modulated to the optical signal using Mach Zehnder modulator (MZM). The resultant optical signal is transformed to electrical using optical to electrical down converter located in a base station and launched onto the wireless channel using wireless transmitter to reach the end user located in its range. At the end user site, the original RF signal is recovered from the received orthogonal subcarriers. **Figure 7** shows the downlink transmission of OFDM signal using RoF technology. OFDM thus improves the capacity of RoF [15].

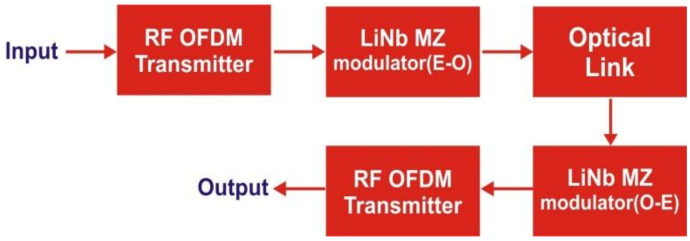

Figure 7. OFDM in Radio over Fiber Systems (Downlink Transmission)

1. Orthogonal Frequency Division Multiplexing (OFDM)

1.1.OFDM Introduction

Due to the increase in demand for high bit rates over dispersive optical transmission medium, the advanced multi carrier modulation techniques have been employed in optical communication. Amongst them, OFDM is considered an efficient technique since it utilizes the available resources effectively and is a successful example of the use of digital signal processing (DSP) techniques. OFDM has been successfully implemented using DSP along wireless channel to mitigate the effects of ISI and multipath fading and is being considered as an auspicious technology in optical domain also. With its implementation to optical communication, due to the demands of high speeds, a possible solution for dispersion compensation has been found. O-OFDM has been adopted mainly due to its resistance from transmission impairments like polarization mode dispersion (PMD) and chromatic dispersion (CD) along with satisfying the demand of high bit rates over dispersive optical transmission medium. In addition, cyclic prefix is added to combat the effects of inter-symbol interference (ISI) and inter-carrier interference (ICI) caused by chromatic dispersion. With advancements in current DSP and VLSI (integrated on a very large scale) circuit technology, OFDM implementation has bypassed all barriers by increasing structural complexity, making it more effective. The implementation complexity of transmitters and receivers has shifted from analog to digital domain. It results in high spectral efficiency as the spectra of orthogonal carriers can overlap and converges to optimum performance [15].

With increase in data rate, error rates also increase and will introduce various interferences like inter symbol interference (ISI). To gain immunity against interference, each symbol would last longer than the channel impulse response i.e. one must slow down the symbol rate to reduce an error rate, which is an obvious task. Unfortunately, the data rate is also reduced by this which is a great demand of the current technology. Thus, there was a great challenge among the researchers to fulfill the almost impossible task of slowing down the symbol rate without slowing the data rate. The answer to this is OFDM. It is a special class of multicarrier technique in which the data stream is converted into many parallel subcarriers with the data rate lower than that of input data stream. These are then modulated individually by digital modulation techniques for transmission such as quadrature amplitude modulation (QAM), Quadrature Phase Shift Keying (QPSK) [17]. It is similar to Frequency Division Multiplexing (FDM) but orthogonality between the parallel subcarriers makes it distinct from general multi-carrier techniques and FDM. Recently, it has been applied to optical communications, but it was successfully implemented for wireless and copper applications since long. Pan and Green showed the first application of OFDM to optical system [18].

1.2.OFDM Principle

The basic principle of OFDM relies on transmitting data by splitting a serial high data rate bit stream into multiple low rate parallel sub-streams such that the symbol time period becomes longer than channel impulse response. These parallel sub-streams are modulated onto different sub-carriers using different modulation techniques such as QAM, QPSK etc. and should be orthogonal to each other. Also, it works on the similar principle of FDM. OFDM utilizes the principle of FDM to transmit these parallel sub-carriers over a single channel, but in a much more controlled way that improves its spectral efficiency. Apart from this, it is distinct from FDM in various manners. FDM transmits data by multiplexing the signals from different sources at different frequencies with a proper separation between each frequency signal. Each signal is transmitted independently without any relationship, coordination or synchronization between the carriers. In an OFDM system, data from single data source is split into multiple sub-channels and should be orthogonal to each other. These sub-channels are transmitted using the same principle as that of FDM. There is time and frequency synchronization between all the subcarriers which allow the careful control of the interference between subcarriers. A certain frequency guard band must be provided between the FDM channels to avoid interference lowering the overall spectral efficiency. However due to the orthogonal nature of the modulation, multiple sub-carriers can overlap but do not cause inter-carrier interference (ICI) and the overlapping improves its spectral efficiency and is the main reason behind OFDM's popularity. **Figure 8** shows the difference between FDM and OFDM [19].

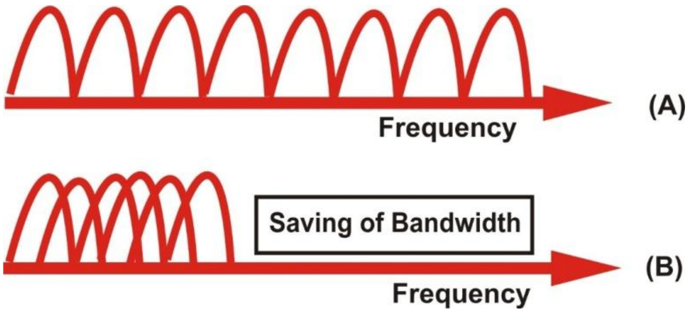

Figure 8. Bandwidth Utilization for FDM and OFDM Multi Carrier Modulation

However, tolerance from chromatic and polarization mode dispersion, compatibility with DSP algorithms and high spectral efficiency makes OFDM attractive choice for optical communication systems.

1.1.OFDM Orthogonality

OFDM transmits a number of sub-carriers. The fundamental aspect of OFDM is that the subcarriers maintain orthogonality with each other. From the general perspective, orthogonality can be viewed if the integration taken for the product of two signals over a certain time period tends to zero. For two sinusoidal functions to satisfy this criterion, their frequencies should be integral multiples of a fundamental frequency. Therefore, orthogonality is defined by:

$$\int_0^{Ts} \cos(2\pi ift).\cos(2\pi jft)\,dt = 0 \quad (1)$$

Where i and j are two integers; f is fundamental frequency; Ts is symbol period.

OFDM subcarrier spacing, Δf is set to $1/NTs$ for orthogonality to be maintained between the subcarriers even when they overlap, and this is called orthogonality condition. Here N and $1/Ts$ represents the number of subcarriers and symbol rate respectively. Orthogonality can be seen in time domain as well as in frequency domain. From the time domain perspective, orthogonality can be viewed if each subcarrier, number of cycles maintains an integer number in single FFT interval i.e. they provide one cycle difference between adjacent subcarriers. In a frequency domain, orthogonality means the peak of the subcarrier occurs at its own center frequency and null at the center frequencies of other subcarriers and the spacing of carriers is set to be $1/NTs$. In other words, the peak of one carrier occurs at null of the other as shown in **Figure 9**. It allows the sub-carriers to space closely even overlapped but still do not cause interference. Orthogonality between the two subcarriers is lost if these criterions are not satisfied [19].

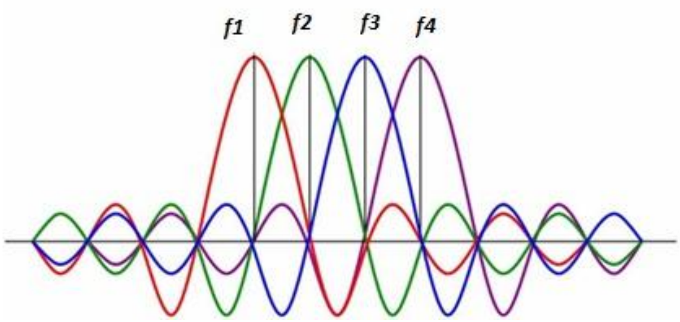

Figure 9. OFDM Spectrum [19]

January-February 2020
ISSN: 0193-4120 Page No. 11714 - 11727

For orthogonality, the inner product is zero for two orthogonal functions with different symbols i.e. zero inter-symbol interference (ISI) and inner product is also zero for orthogonal functions with different subcarriers i.e. zero inter-carrier interference (ICI).

1.1.Optical-OFDM

Recently, OFDM is applied in optical communications but now it is seeking a great attention of the researchers for its performance in optical channel for dispersion compensation and high rates. It greatly combats chromatic dispersion in optical media. With the use of DSP technology in OFDM, it comes out as an efficient technique for data processing. It leads to an increase in the transmission rates every year, several Tb/s rates has been experimentally demonstrated. For the efficient working of the OFDM system, there must be linearity between the transmitter IFFT input and receiver FFT output. Optical system can be categorized into two broad groups– multi-mode and single-mode fiber systems transmitting many optical modes and only optical mode of the signal respectively. Multi-mode fiber systems are usually implemented by intensity modulation where the multiple modes of the signal transmitted are linear in terms of intensity. As we know that RF-OFDM signals are bipolar (having both positive and negative values) but intensity modulation does not support bipolar signals. intensity of the light signal which can only be non-negative (unipolar). Therefore, to transmit OFDM signal on optical carrier using IM/DD link, it has to be converted to real and positive signal. Possible alternatives have been developed for this purpose to convert a bipolar signal to a unipolar signal– 'biased OFDM (B-OFDM) and clipped OFDM (C-OFDM). In BOFDM sufficiently large bias component (usually a dc bias) can be added with OFDM signal thus leading to a formation of non-negative signal. But due to the large PAPR of OFDM signal, only a small portion of the negative part is clipped leading to the distortion in the signal. In C-OFDM bias component is added in OFDM signal to clip negative portion of the OFDM signal at zero level. Whereas, the single mode fiber systems can be easily
implemented using linear field modulation where the signal is represented by optical field and this form of the signal can also be known as an unclipped-OFDM (U-OFDM) [20].

1.2.Mathematical analysis of OFDM

OFDM signals can be represented as a sinc function formed by modulating the sinusoidal carrier with a rectangular wave of information symbol. OFDM signal can generally be represented as a group of modulated carriers that can be simultaneously transmitted as follows[23]:

$$s(t) = \mathrm{Re}\left\{ \sum_{n=-\infty}^{\infty} \sum_{k=0}^{N-1} x_{n,k} g_k(t - nT_s) \qquad t = [0, T_s] \right. \tag{2}$$

Where, $$g_\kappa(t) = \begin{cases} e^{j2\Pi f_k t} & t \in [0, T_s] \\ 0 & otherwise \end{cases} \tag{3}$$

And, $$f_k = f_0 + \frac{k}{T_s} \quad , \; k = 0 \ldots N-1 \tag{4}$$

And, $$X_{n,k} = a_{n,k} + jb_{n,k} \tag{5}$$

Considering equations (2), (3) and (5), we get

$$s(t) = \sum_{n=-\infty}^{\infty} \sum_{k=0}^{N-1} \{a_{n,k}\, cos(2\Pi f_n(t - nT_s)) - b_{n,k}\, sin(2\Pi f_n(t - nT_s))\} \tag{6}$$

If there is only one OFDM symbol (i.e. $n = 0$), it can be simplified as:

$$s(t) = \sum_{k=0}^{N-1} \{a_k\, cos(2\Pi f_k t) - b_k\, sin(2\Pi f_k t)\} \tag{7}$$

Where, *Ts* is OFDM symbol duration.

Xn,k is transmitted data on the *nth* symbol of the *kth* carrier, or the symbol transmitted on the
kth subcarrier in the *nth* signaling interval, each of duration *T*.
gk is the waveform for the *kth* subcarrier,
N is number of symbols in a block which are grouped to be transmitted in parallel,
fk is the frequency of *kth* subcarrier, and *f0* is the lowest frequency.

Orthogonality Condition

January-February 2020
ISSN: 0193-4120 Page No. 11714 - 11727

$$\int_0^{T_{os}} g_n(t) * g_m(t)\, dt \qquad n \neq m \tag{8}$$

In our case

$$\int_0^{T_{os}} cos(2\Pi nft).cos(2\Pi mft)dt = 0 \qquad n \neq m \tag{9}$$

$$\int_0^{T_{os}} e^{2\Pi fnt} e^{-2\Pi fmt} dt = 0 \qquad for \;\; n \neq m \qquad where \; f_k = k/T_{os} \tag{10}$$

OFDM in terms of FFT Technique:

Let X_n is the modulated data, where $n = 0, 1$……….. $(N - 1)$

OFDM signal is represented using IFFT as,

$$x_n = \frac{1}{N} \sum_k^{N-1} X_k e^{\frac{i2\pi nk}{N}} \qquad ; 0 \leq n \leq N-1 \tag{11}$$

Demodulated stream can be expressed using FFT as:

$$Y_k = \sum_{n=0}^{N-1} y_n e^{\frac{-i2\pi nk}{N}} \qquad ; 0 \leq k \leq N-1 \tag{12}$$

1.1.Optical-OFDM Signal Processing

The OFDM optical system is made up of five operational frames. OFDM transmitter for producing the OFDM signal from the bit stream; RF to optical up converter for converting the RF (electrical) signal to optical by modulating the RF signal light; optical media for transmitting the optical signal from the channel; optical to RF down converter for converting the optical signal to RF using photodiode; OFDM receiver for detecting the original OFDM signal bit streams. **Figure 10** displays the basic block diagram for the optical OFDM (O-OFDM) system.

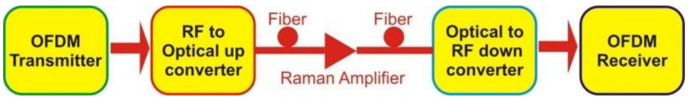

Figure 10. Optical-OFDM System

Figure 11 Displays the O-OFDM Transmitter and receiver diagram showing all the operational frames. OFDM modulation is based on transmitting high bit rate data streams by dividing into a number of low rate streams each modulated by different modulation formats such as binary phase shift keying (BPSK), quadrature phase shift keying (QPSK) or quadrature amplitude modulation (QAM) that may be 4QAM, 16QAM, 64QAM, etc.

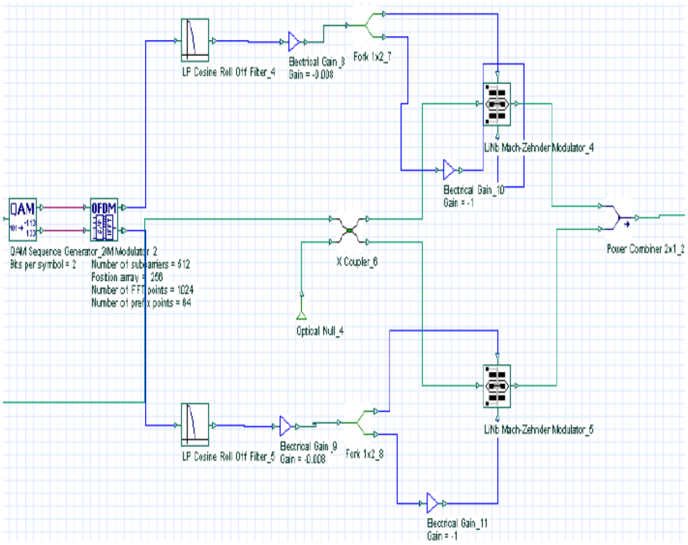

Figure 11. (a) Diagram of O-OFDM Transmitter System

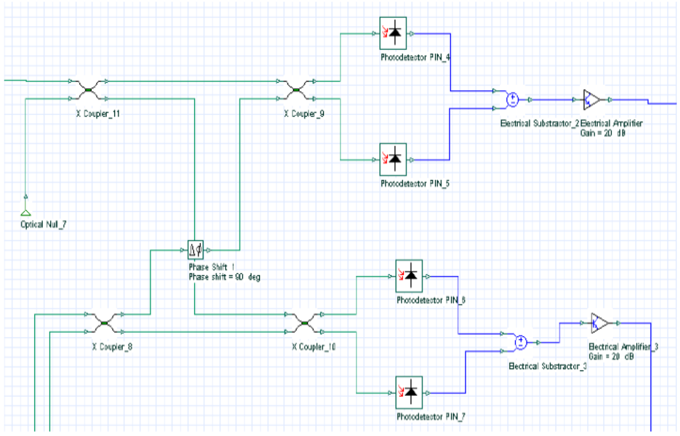

Figure 11. (b) Diagram of O-OFDM Receiver System

RF-OFDM transmitter consists of a digital data source that provides the bit streams which is split into multiple lower rate parallel bit streams using serial to parallel converter. Low data rate of each parallel stream implies long symbol periods, and this greatly reduces ISI. The parallel bit streams are a block of bits used for m-ary mapping such as PSK, QAM for instance two bits in a symbol represents four combinations and hence 4-QAM. Coding and modulation of the signal can be performed side by side such as binary to gray coding and QAM modulation. These blocks of bits are mapped to different constellations points and each block is represented by an information symbol. A QAM symbol represents the baseband I/Q components in

January-February 2020
ISSN: 0193-4120 Page No. 11714 - 11727

the complex plane. Then IFFT transformation is used to convert complex QAM symbols to OFDM subcarriers (OFDM symbols). Orthogonality to the subcarriers is introduced in this stage. In OFDM transmission (which is a multi-carrier technique), we need separate oscillators tuned at orthogonal frequencies to modulate each QAM symbol into orthogonal subcarriers. But the use of IFFT eliminates the need of multiple oscillators to assign different frequencies to each QAM symbol. By using IFFT/FFT in OFDM transmitter and receiver, systems can do modulation in digital form. Moreover, it is used to choose the functions that are orthogonal to each other and hence produces the OFDM signal. IFFT properties such as baud rate, number of subcarriers and cyclic prefix must suit the properties of FFT. It also converts an OFDM frequency domain signal to its time domain counterpart as signal processing in the frequency domain is simple but should be translated to the time domain for transmission. In each OFDM subcarrier, a cyclic prefix is used to mitigate the effects of dispersion. It consists of a small portion of the data taken from the end of the data part of each OFDM symbol and appended to the beginning of each symbol and contains redundant information as shown in **Figure 12**.

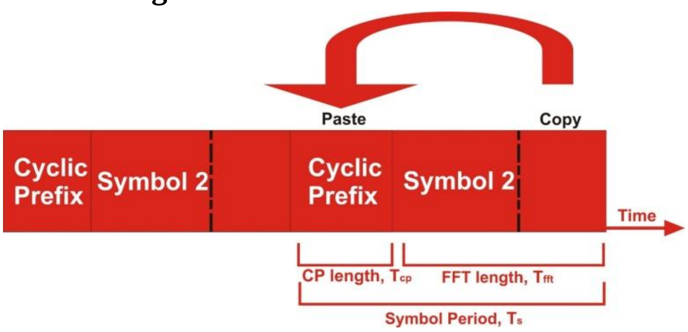

Figure 12. Cyclic Prefix

As we all know that dispersion from optical fiber causes inter-symbol interference (ISI). However, only the beginning and ending portion of each OFDM symbol is affected by ISI leaving the center portion intact so by adding redundant information at the beginning of symbol we can reduce dispersion. To avoid the dispersion effects effectively, its length should be more than the total delay spread caused due to the multipath fading and dispersion. In the other context, adding CP increases bandwidth. The OFDM signal is then modulated to up convert the frequency from baseband to RF (carrier frequency). A complete OFDM symbol is framed by transforming it to serial format consisting of multiple OFDM symbols. **Figure 13** shows the RF-OFDM transmitter.

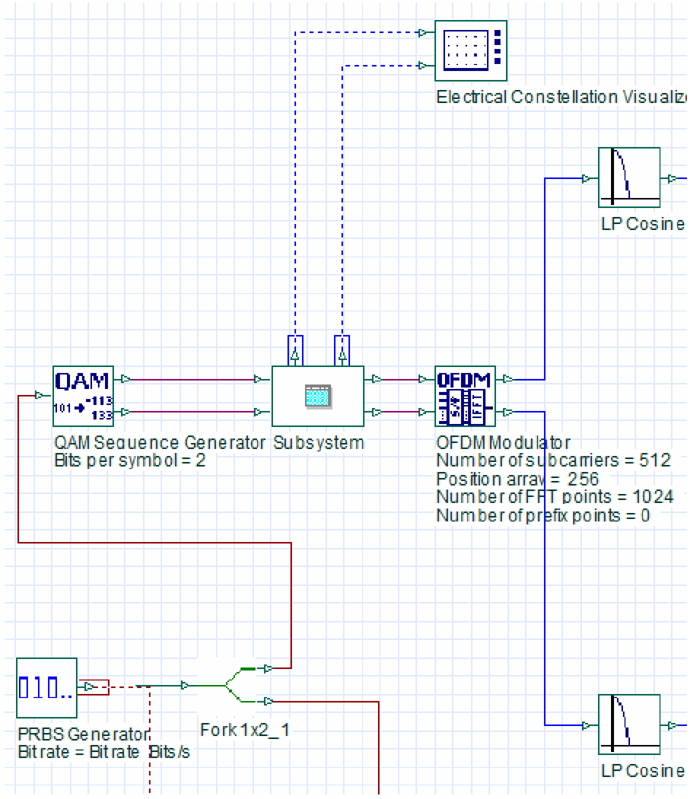

Figure 13. RF-OFDM Transmitter

We receive RF-OFDM signal at the OFDM transmitter output, which is then converted to optical form using RF to optical up converter. Through direct or external modulation (through Mach Zehnder modulator (MZM)), the laser output is transformed to the optical domain in RF to optical up converter. This optical OFDM signal is propagated by means of optical media. Optical amplifiers can be used to increase the signal strength for long distance transmission. Optical to RF down converter is used in the receiver segment to transform the optical-OFDM signal back to its electrical counterpart, i.e. Signal from RF-OFDM. Using the image detector, this is achieved. At this point of time, OFDM

January-February 2020
ISSN: 0193-4120 Page No. 11714 - 11727

demodulation process starts. To start the OFDM reception, RF modulated OFDM signal should be split to the multiple streams for the detection of each subcarrier separately. This serial to parallel conversion at the transmitter and parallel to serial conversion at the receiver is necessary to modulate the signals at lower rate which is useful to avoid interference in the signal and is a characteristic of the OFDM. Instead, by quadrature mixing down the RF modulated OFDM signal using RF demodulator, the RF signal is converted into baseband (to access the frequency). Two7-pole low-pass Bessel filters are used with the center frequency equal to that of the carrier to filter out the representation of the signal at twice the carrier frequency and harmonics induced by the downward shifting of the frequency. The cyclic prefix is then discarded, and the remaining signal is passed to calculate FFT on the OFDM signal via FFT conversion, resulting in a QAM signal. The QAM signal is passed through the QAM demodulator to receive the initial bit stream signal followed by the serial converter parallel [19]. RF-OFDM receiver is shown in **Figure 14**.

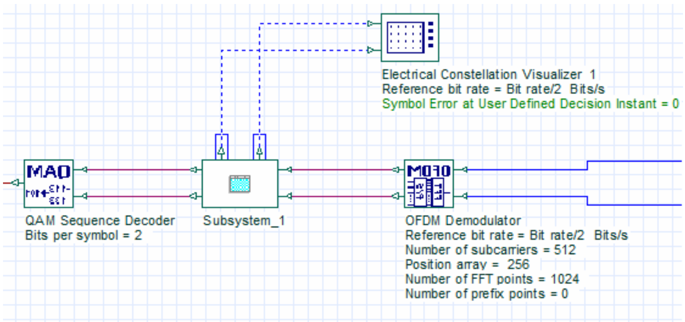

Figure 14. RF-OFDM Receiver

1.1. Merits of OFDM

High spectral efficiency. Signals are overlapped to each other and there is no need to provide guard band between the two signals and hence increases spectral efficiency.

Natural protection against ISI. The serial bit flow in OFDM system is divided into multiple streams with each symbol's data rate lower than a single high data rate stream. The low rate modulation makes the symbol duration longer than the channel's impulse response. ISI is decreased in this way.

Chromatic and polarization mode dispersion tolerance. In optical communication, OFDM is introduced mainly because of its sensitivity to chromatic dispersion (CD) and dispersion of the polarization mode (PMD). In addition, we can further reduce the dispersion by using the cyclic prefix.

Natural compatibility with DSP based implementation. Using DSP technologies, transmitter and receiver design complexity has changed from analog to digital realm. In addition, OFDM generation and detection becomes computationally more effective with the development of FFT techniques. In the transmitter and receiver parts respectively, IFFT and FFT techniques are used. This replaces a variety of oscillators, modulators and modulators with a single oscillator.

Advantages in bandwidth allocation and control.

However, O-OFDM systems offer a few drawbacks also:

1.2.High Peak to average power ratio (PAPR)

OFDM signal has high amplitude fluctuations because the subcarriers of OFDM symbol may add up constructively or destructively. The high PAPR reduces the nonlinearity tolerance and are therefore unsuitable for non-linear systems. High PAPR in OFDM symbols can cause spreading of spectrum, intermodulation and harmonic distortions. PAPR increases with increase in the number of subcarriers. The PAPR of OFDM is given by:

$$PAPR = \frac{\max\{|s(t)|^2\}}{mean\{|s(t)|^2\}} \quad (13)$$

January-February 2020
ISSN: 0193-4120 Page No. 11714 - 11727

Theoretically, the maximum value of PAPR is 10*$\log_{10}$ (Nsc). For instance, the maximum PAPR of the OFDM signal with 8 subcarriers will be 9 dB.

Furthermore, O-OFDM systems produces frequency and phase offset that can cause attenuation in subcarriers called as inter-carrier interference (ICI).

2. Conclusions

The performance of a RoF system using OFDM broadband was performed in this review paper, analyzing the impairments of the transmitter, namely linear and nonlinear distortion, frequency noise, memory effect and to what degree the above limitations were compensated by techniques already implied to OFDM technology. This research provides a comprehensive review of the various developments in the field of RoF systems and the emergence of new techniques. An analysis of these techniques gives an idea of how the different parameters such as fiber length, input power, losses suffered, modulation formats etc. have influenced techniques such as OFDM in future RoF systems successfully implemented.

References

[1] R. Kompfner, “Optical Communications,” Science, vol. 150, pp. 149-155, October 1965.
[2] S. E. Miller and L. C. Tillotson, “Optical Transmission Research,”’ Appl. Opt.’, vol. 5, pp. 1538-1549, October 1966.
[3] S. E. Miller, ‘‘Optical Communications Research Progress,” Science, vol. 170, pp. 685695, November 1970.
[4] K. C. Kao and G. A. Hockham, “Dielectric-Fiber Surface Waveguides for Optical Frequencies,” hoc. IEE, vol. 113, pp. 1151-1158, July 1966
[5] J. Hou and D. C. O'Brien, "Vertical handover-decision-making algorithm using fuzzy logic for the integrated Radio-and-OW system," Wireless Communications, IEEE Transactions on, vol. 5, 2006, pp. 176-185.
[6] S. Ghosh. "Emergent technology based Radio Access Network (RAN) design framework for next generation broadband wireless systems," M.S. thesis, Dept. Comp. Sci. and Eng., Univ. Texas at Arlington, 2004.
[7] T. Kamalakis, I. Neokosmidis, A. Tsipouras, S. Pantazis and I. Andrikopoulos, "Hybrid free space optical/millimeter wave outdoor links for broadband wireless access networks," in Personal, Indoor and Mobile Radio Communications, IEEE 18th International Symposium on, 2007, pp. 1-5.
[8] M. Safari and M. Uysal, "Relay-assisted free-space optical communication," in Signals, Systems and Computers, Forty-First Asilomar Conference on, 2007, pp. 1891-1895.
[9] J. Akella, C. Liu, D. Partyka, M. Yuksel, S. Kalyanaraman and P. Dutta, "Building blocks for mobile free-space-optical networks," in Wireless and Optical
Communications Networks, Second IFIP International Conference on, 2005, pp. 164-168.
[10] O. Bouchet, M. El Tabach, M. Wolf, D. C. O'Brien, G. E. Faulkner, J. W. Walewski, S. Randel, M. Franke, S. Nerreter, K. D. Langer, J. Grubor and T. Kamalakis, "Hybrid wireless optics (HWO): Building the next-generation home network," in Communication Systems, Networks and Digital Signal Processing, 6th International Symposium on, 2008, pp. 283-287
[11] D. O'Brien, "Cooperation in optical wireless communications," in Cognitive Wireless Networks: Concepts, Methodologies and Visions Inspiring the Age of Enlightenment of Wireless Communications, F.H. P. Fitzek and M. D. Katz, Eds. Springer, 2007, pp. 623-634
[12] J. P. Javaudin and M. Bellec, "Technology convergence for future home networks," in Wireless Days, 2008, 1st IFIP, 2009, pp. 1-5
[13] R. Ramirez-Iniguez and R. J. Green, "Indoor optical wireless communications," in Optical Wireless Communications, IEE Colloquium on, 1999, pp. 14/1-14/7.
[14] J. C. Juarez, A. Dwivedi, A. R. Mammons, S. D. Jones, V.Weerackody and R. A. Nichols, "Free-space optical communicationsfor next-generation military networks," Communications Magazine,IEEE, vol. 44, 2006, pp. 46-51.
[15] Yoon-Khang Wong, S.M. Idrus, and I.A. Ghani “Performance Analysis of the OFDM Scheme for Wireless over Fiber Communication Link”,

International Journal of Computer Theory and Engineering, Vol. 4, No. 5, October 2012.
[16] Ajay Kumar Vyas, Dr. Navneet Agrawal, "Radio over Fiber: Future Technology of Communication", International Journal of Emerging Trends and Technology in Computer Science (IJETTCS), Vol. 1, Issue
2, July-August 2012, ISSN 2278-6856.
[17] R. Karthikeyan and Dr. S. Prakasam, "A Survey on Radio over Fiber (RoF) for Wireless Broadband Access Technologies", International Journal of Computer Applications (0975-8887), Volume 64, No. 12,
February 2013.
[18] Harada, H. and Prasad, R. "Simulation and Software Radio for Mobile Communication", London: Artech House Publishers, 2002.
[19] Nee, R.V. and Prasad, R. "OFDM for Wireless Multimedia Communications", UK: Artech House
Publishers, 2000.
[20] W. Shieh, H. Bao, and Y. Tang, "Coherent optical OFDM: Theory and design," Opt. Exp., vol. 16, pp. 842–859, Jan. 2008.