Performance Analysis of Radio over Optical Fiber System with OFDM Using Multiplexing Techniques

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Abstract

Radio over Fiber (RoF) system is a promising technique for applications of microcell and picocell to deploy wireless data networks in the future. It is represented an integration of microwave and optical networks, which its uses optical fiber as a backbone technology because of the tremendous advantages it offers. However, the performance of RoF systems can deteriorate severely because of the nonlinear effects of the channel. In addition, Orthogonal Frequency Division Multiplexing (OFDM) is being proposed as a standard for broadband wireless networks for deployment with RoF systems to facilitate overall system performance. The increased of demand for high speed data rate and high capacity of bandwidth because of recent developments in technology in bandwidth for access networks. The combination of RoF and OOFDM techniques has resulted in a high data rate at lower cost of wireless networks. Thus, this paper illustrates that the performance of RoF optical link has been analyzed with and without Optical Orthogonal Frequency Division Multiplexing (OOFDM) for multi-channel through combining two multiplexing techniques, such as; Subcarrier Multiplexing (SCM) and Wavelength Division Multiplexing (WDM). The system uses the hybrid WDM-SCM-OFDM PON architecture combined with RoF technology. The performance of network has been compared with different digital quadrature amplitude modulation schemes (such as: 4-QAM, 16-QAM and 64-QAM) for 20 km optical fiber length and for three data rates (5, 7 and 10) Gbps. The performance analysis is based on the optical spectrum of transmitted signal, constellation diagrams and symbol error for 4 and 32 channels. Our result shows that the 16-QAM-OFDM performs better than 4-QAM-OFDM and 64-QAM-OFDM modulation schemes. In addition, 64-QAM-OFDM gives highest value of noise ratio with a slight difference in signal-to-noise ratio for 16-QAM-OFDM. The proposed system link has been modeled and simulated using a commercial optical system simulator named opt system "version 14" software package.

Keywords: Radio over Fiber (RoF), Orthogonal Frequency Division Multiplexing (OFDM), Subcarrier Multiplexing (SCM), Waveform Division Multiplexing (WDM).

INTRODUCTION

Nowadays, there is an urgent need in optical communication to meet the service requirements of ultra-large capacity and ultra-high speed for wireless access network because of its spectrum availability and digital signal processing equipments. However, the current wireless signals suffer from uncompromising loss along the existing transmission channel in addition to loss of free space. Using RoF to provide radio access has some advantages, such as: low-cost remote antenna units, the ability to deploy small and ease of upgrade for future potential exploration. To provide low power consumption and large bandwidth while reducing the costs of deployment and maintenance of wireless networks, RoF system seems to be a promising candidate, which will be widely used for many communication standards, such as: Wi-Fi networks, digital subscriber loop (DSL), Worldwide Interoperability for Microwave Access (WiMAX) and digital video and audio broadcasting standards [1].

RoF system is a very important technique for the wireless access network, where it is used to transmit millimeter and microwave waves by optical fiber for short and long distances. It is also used to support the current 4th generation mobility network and WLAN. However, RoF represented integration of optical network and RF, as well as it is used to increase the channel capacity and decreasing the power consumption and cost. It is also used to support the current 4th generation mobility network and WLAN. However, RoF represented integration of optical network and RF, where it is used to increase the channel capacity as well as decreasing the power consumption and cost. This system provides radio access has a number of applications in the recent and the next generation of wireless systems. This includes, Remote Site (RS) and Central Site (CS), which connects to an optical fiber link, where the signal is transmitted between RS and CS in the optical band by RoF network [2]. Thus, RoF system can be the answer to many of the wireless network demands because of it is provides low-cost configuration. However, due to the optical modulated signals are transmitted to the base station carry to the fiber without big losses and reach the mobile user by the RF transmission, thus it is an appropriate technology for wireless network.

Orthogonal frequency division multiplexing (OFDM) is chosen as a modulation technique for wireless communications because it provides large data rates with sufficient durability to impairments the radio channel. However, OFDM is a transmission scheme utilizes multiple sub-carriers to transfer the serial high rate data streams into the multiple parallel low rate data streams. Hence, prolongs the duration of the symbol and thus helping to eliminate the Inter Symbol Interference (ISI) [3] [4]. Usually, a single mode or multimode optical fiber is utilized as the transfer method between the base stations (B.Ss) and the antenna, where there
is an electronics rack. However, the study described in the current paper attempted to provide the performance of RoF optical link which has been analyzed with and without OFDM for multi-channel by combining two multiplexing techniques, such as; SCM in RF side and WDM in optical side for different lengths of optical fiber, data rate and different modulation schemes.

Thus, this paper is organized as follows: Section 2 offers the analysis of the deployment of RoF system including the RoF system concept, multiplexing schemes in RoF for wireless communications and OFDM concept. In Section 3, presents system design for RoF which include proposed simulation setup for the SCM and SCM/WDM RoF. Section 4 provided a discussion on the performance of the proposed system with simulation results. Section 5 presents brief concluding remarks of the study.

DEPLOYMENT OF RoF SYSTEM

This section introduces information about the multi-channel RoF system and then, it provides a survey of the two multiplexing techniques, such as; WDM and SCM that use in this paper, so that analyzing how the OFDM are effected on the performance of system can be described also in this section.

RoF System

RoF is a wireless combination with fiber optic networks, where the RF signals are distributed from a central location to the units of remote antenna. However, RoF Technology is the integration of optical networks and microwave, which represents a possible solution to increase capacity, mobility and reduce the costs in the access network as shown in Figure 1 [5]. Wireless signals are routed in optical form between the main station and different other base stations [6–8]. Base stations transmit data to mobile stations, which falls within the base station range. The optimal use in RoF of the transferring the signal is utilized through ensuring minimal loss through the transmit of RF signals to the units of remote antenna. The signal processing is handled in the RoF, which offers some advantages, such as; ease in equipment sharing and ease of operation.

The points of low power radio access ensure improved frequency reuse and better system capacity, where RoF technology connects the points of radio access to the control stations [9]. The architecture of the RoF technology contain of a network system which uses an antenna network. However, the signal processing at these antenna’s demultiplexing is done through transmitting the RF signals to the control stations by the optical fiber. However, RoF may have advantage, such as; less attenuation, low complexity, lower cost, large bandwidth and easy installation and flexibility. The concept of RoF means that the transfer of information on the optical fiber will be through adjusting light with radio signal. This modulation can be made directly at intermediate frequency or with radio signal. RoF technique has the capability of the backbone of the wireless access network. However, this architecture can give several advantages, like transparency and scalability, reduced the complexity of antenna location and radio carriers can be allocated dynamically to the locations of various antenna [10].

A These systems will need to provide data transfer capacities far beyond the standards of current wireless systems to provide integrated broadband services. However, some of the main wireless standards today’s are 3G mobile networks, which offers up to 2 Mbps and operating about 2 GHz and Wireless LAN, which offers up to 54 Mbps and works at carrier frequencies about 2.4 and 5 GHz. In addition, another recent standard is IEEE802.16 or WiMAX, which aims to bridge the last mile by the mobile as well as fixed wireless access to the end user at the frequencies which lies between 2 and 66 GHz. The need to increase the capacity per unit space leads for smaller radio cells and higher operating frequencies above 6 GHz especially in internal applications where the high operating frequencies are encounter extremely high losses by the walls of the building. It is necessary to make the units of radio antenna as simple as possible to reduce the maintenance and installation cost of such systems [11].

Figure 1: Basic diagram of RoF technology [11].

Multiplexing Schemes in RoF for Wireless

Different multiplexing schemes in field of ROF for wireless communication are briefly described in this section:

A. Waveform Division Multiplexing (WDM)

The basic concept of WDM technology is to combine multiple optical channels with the various wavelengths which comes from various optical sources into a single fiber through utilized multiplexers at the transmitter side as well as demultiplexers in the receiver side to divide the WDM channels. However, WDM technology is an effective way can be used in the optical fiber feeder network to increase the capacity of RoF systems, increase the usable bandwidth of the fiber as well as increases the number of base stations powered by the central office. Furthermore, the topologies of the WDM-RoF networks are similar to the other optical networks.
topologies, like bus network, ring network and star network [12,13].

It is a passive device which combines light signals with various wavelengths that comes from multiple fibres to a single fibre. This needs dense wavelength division multiplexers (DWDM). Optical (analog) techniques of multiplexing are utilized through these devices to increase the capacity of carrying of fibre networks above levels, which are achieved through the use of time division multiplexing (TDM). Nowadays, the distribution of RoF signals which illustrates in Figure 2 using WDM technology has becomes very important. However, for a single fibre, such systems are able to achieve capacities of 1 Tb/s. Single channel has bit rates raised to 10 Gb/s and channel rates of 40 Gb/s of the systems available at the commercial level. It is possible to reduce the spacing of channel to 50 GHz or even to 25 GHz which makes possible to use channels one hundred in number. But if the reduction in spacing of channel will be 50 GHz rather than 100 GHz, this will make upgrading of the systems running at 40 Gb/s more difficult due to non-linear effects in nature [14].

**Figure 2:** RoF system through used WDM technology [14].

**B. Subcarrier Multiplexing (SCM)**

SCM technique is one of the multiplexing techniques which can be used in optical system to increase the bandwidth utilization efficiency. The SCM is more sensitive to noise effects, which limits the data rates and maximum subcarrier frequencies. The basic configuration of the SCM optical system is shown in Figure 3. The multiple Radio Frequency (RF) signals in this technique of RoF system are multiplexed in frequency domain then transmitted through a single wavelength. However, the combination of SCM and WDM techniques may provide greater flexibility for high speed optical transmission with high dispersion tolerance and high optical bandwidth efficiency [15-18].

Optical subcarrier multiplexing (OSM) is a system in which more than one signals are being multiplexed in the radio frequency domain then transmitted through the use of single wavelength. Thus, the devices with microwave are more mature than optical devices and the analog cable television in fiber optic systems is the common application of this scheme. Frequency selection in the microwave filter and stability is much better in the microwave oscillator compared to the optical. Thus, in the radio frequency domain, the coherent detection becomes easier due to RF oscillators with low phase noise compared to the advanced modulation formats and optical domain which are applicable simply [14].

**OFDM TECHNIQUE**

OFDM is an effective solution to inter-symbol interference problem caused through a dispersive channel, thus, it is utilized widely in communications systems. In addition, OFDM is characterized of is that it conveys complexity of transmitters and receivers from the analog to the digital domain. However, the basic concept of OFDM is a method of divide a stream of high data rate into multiple less data rate streams and then transmitted in the same time through a number of orthogonal subcarriers. As a result, reduce the relative amount of dispersion in time caused through dispersive channels like optical fibers. OFDM based design has an inherent ability to include an extended guard time periodically in each OFDM symbol. The OFDM symbol is periodic extension the guard time to avoid and removes inter carrier interference. However, an OFDM signal consists of the sum of the subcarriers that are modulated through the use of quadrature amplitude modulation (QAM) or phase shift keying (PSK) [19-21].

**SYSTEM DESIGN**

RoF system consists of three main parts which are; transmitter, fiber channel and receiver. However, the transmitter part contains two main sides, such as; electrical side for generating RF signal with SCM and optical side for generating optical signal with WDM. While the receiver part contains the RF side and optical. This section offers the design of RoF system utilize different types of modulation schemes, such as: 4-QAM, 16-QAM and 64-QAM with and without OFDM technique in multi-channel transmission through used WDM and SCM techniques.
A. Model for SCM-RoF System

In this section, 4-RF channels (2.4 GHz, 5.8 GHz, 10 GHz and 15 GHz) are simulated through utilizing 4-QAM, 16-QAM and 64-QAM modulation schemes with OFDM technique at 5 Gbps data rate. The proposed simulation setup for the SCM with (4-QAM-OFDM) and (64-QAM-OFDM) RoF systems is shown in Figure 4 and Figure 5, respectively. However, for the transmitter part in these figures, in start, the data bits are encoded after that converted into a constellation map of a well-known modulation scheme used in this work. In OFDM technique, the data is interpreted as a frequency-domain data and it is later converted to the time domain signal through IFFT process, after that, IFFT output is sent to the channel after the addition of cyclic prefix (CP). The OFDM time signals are then converted to the appropriate analog form through using D/A converters as well as modified the laser diode creating an optical signal pass by the optical link to finally move into a wireless channel. In addition, the combiner is utilized to combine four input signals into a single output signal. At the receiver part, after the signal converted from an optical form into an electrical form by a photodetector, it is passed across Fork to reiterate the input signal into four output signals. An electrical amplifier in this system is used to recompense the power which is lost due to the fiber attenuation.

(a) Proposed simulation setup for the transmitter part (SCM-4QAM)

(b) Proposed simulation setup for the receiver part (SCM-4QAM)

Figure 4: Proposed simulation setup for the SCM (4QAM-OFDM-RoF) system
B. Model for (SCM/WDM)-RoF System

In this section, the combination of WDM and SCM techniques for RoF system are utilized to multiplex 8-optical channels. Each optical channel consists of four RF channels at 5 Gbps data rate for each RF channel, and thus a 32-channel RF is produced. However, in this model, three modulation schemes, such as; 4-QAM-OFDM, 16-QAM-OFDM and 64-
QAM-OFDM) can be utilized. Figure 6 shows the simulation of SCM/WDM RoF system.

RESULTS AND DISCUSSIONS

In this section, the simulation results of multi-channel of RoF system have conducted for the SCM technique and then combination of SCM with the WDM technique. However, in this simulation, QAM signal which uses (4, 16 and 64) bits per symbol is used. Then, number of bits in each symbol is (2, 4 and 6) and the constellation result is given by formula 2n. However, this study assumes that all simulations parameters setting for the proposed system are available and fully known as shown in Table 1, while the rest will be assigned to the default value of the optisystem software.

### Table 1. Simulations parameters setting

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
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<tbody>
<tr>
<td>Data rate</td>
<td>(5, 7 and 10) Gbps</td>
</tr>
<tr>
<td>Wavelength for CW laser</td>
<td>193.1 THz</td>
</tr>
<tr>
<td>Number of subcarrier</td>
<td>128 and 1024</td>
</tr>
<tr>
<td>Radio frequency</td>
<td>(2.4, 5.8, 10 and 15) GHz</td>
</tr>
<tr>
<td>Fiber length for the transmitting signals</td>
<td>10 up to 50 km</td>
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</table>

#### A. SCM for RoF Link with 4-QAM Modulation Scheme

The results for the radio frequency (RF) spectrum and the optical spectrum modulation of the transmitted and received signals for the SCM-RoF-OFDM system of 4-QAM scheme after 20 km with more harmonics at the sideband of the spectrum are shown below in Figure 7. In other words, the results of both optical signals with amplification before and after filtering based on optical transmission link in the optical domain are shown in these figures. The spectrum of SCM signal is for four data streams, where the four data streams of bit rate 5 Gbps are modulated into four RF subcarriers of frequencies (2.4, 5.8, 10 and 15) GHz which are multiplexed in RF domain. In addition, this SCM composite signal is then modulated on to a signal optical carrier of frequency 193.1 THz. However, a spectrum enhancement option is needed through optical amplification because of poor quality OFDM spectrum resulting from the baseband and transmission path. The performance is mainly hampered through the system transmission channel, the accumulated amplifier noise and the components of internal performance system. The optical spectrum modulation of the RF carrier produces single sideband signals after filtering. Moreover, after filtering, the optical spectrum modulation of the RF carrier produces a signal with single sideband. The architectures of a transmitter side with an actual signal is proposed in this work for causing the RF OFDM signal to be a complex intermediate frequency in order to suppress one of the sidebands with an optical filter. Furthermore, at the reception side, photodiode is used to detect the optical signal and then demodulated it. In addition, to remove the single-side band, the RF frequency must be chosen in this work.

The received signal power versus optical fiber length for SCM-RoF link with two different data rates, such as; (5 and 10) Gb/s for 4-QAM modulation scheme and OFDM techniques.
shown in Figure 8. The performance of SCM-RoF system with 10 Gb/s is better than the performance of this system with 5 Gb/s. In addition, the RF signal power of 4-QAM-OFDM system at 80 km optical fiber length for data rate 10 Gb/s equal to 88 while it is equal 85 for 5 Gb/s at the same optical fiber length. It can be concluded that the RF signal power decreases with the increase of fiber length for the different values from data rates.

Figure 9 shows the constellation diagram of the SCM-RoF link for the first and fourth RF channels and 4-QAM-OFDM after 20 km of fiber optic length with different values from the data rate, such as; (5, 7 and 10) Gbps. The bandwidth of the RF-channels increases by growing the data rate and thus overlap the RF-channels with each other. However, the signal constellation of the transmitter is taken from the output of the M-ary pulse generator.
Figure 9: The constellation diagram of SCM-RoF-OFDM system for 4-QAM scheme
B. SCM-RoF Link with 16-QAM Modulation Scheme

The RF spectrum and the optical spectrum of the transmitted and received signals for the SCM-RoF-OFDM system of 16-QAM scheme after 20 km at 5 Gbps is shown in Figure 10. The SCM composite signal is modulated on to a signal optical carrier of wavelength 1.5525 μm.

Figure 12 shows received signal power versus the length of the optical fiber of the SCM-RoF link for 16-QAM modulation scheme and OFDM technique for different data rates. From this figure, we can see that the signal power has increased with lower the data rate. As mentioned before in Section 4.1, the performance of SCM-RoF system for 16-QAM scheme with 10 Gb/s is better than the performance of this system with 5 Gb/s. Moreover, the RF signal power of 16-QAM-OFDM system at 80 km optical fiber length for data rate 10 Gb/s equal to 91.5 while it is equal 87 for 5 Gb/s at the same optical fiber length.

The constellation diagram of the SCM-RoF link for the 16-QAM modulation scheme with OFDM technique for the first and fourth RF channels at 5 Gbps and 10 Gbps bit rates after 20 km of fiber length is shown in Figure 11. The bandwidth of the RF channels of the 4-QAM scheme is bigger than the bandwidth of RF channels of the 16-QAM scheme, therefore, the interference between RF-channels was lowered.
Figure 12: Signal power vs length of SCM RoF-OFDM system for 16-QAM scheme

(a) The constellation diagram of SCM-RoF-OFDM system for the channel 1

(b) The constellation diagram of SCM-RoF-OFDM system for the channel 4

Figure 11: The constellation diagram of SCM RoF-OFDM system for 16-QAM scheme

C. SCM-RoF Link with 64-QAM Modulation Scheme

Figure 13 shows the RF spectrum and the optical spectrum of the transmitted and received signals of the SCM-RoF-OFDM system for 64-QAM at 5Gbps data rate after 20km. The SCM composite signal is modulated on to a signal optical carrier with the same wavelength for the 16-QAM scheme. While the constellation diagram of the SCM-RoF link for the 16-QAM modulation scheme with OFDM technique for the first and fourth RF channels after 20 km of fiber length at 5 Gbps bit rate is shown in Figure 14.
Figure 13: The RF spectrum and optical spectrum of SCM RoF-OFDM system for 64-QAM scheme

(a) RF spectrum of the transmitted and received signals

(b) Optical spectrum of the transmitted and received signals

Figure 14: The constellation diagram of SCM-RoF-OFDM system for 64-QAM scheme
D. SCM/WDM System Model for RoF Link

In this section, the simulation results are presented for the collecting of WDM with SCM techniques for RoF link. However, Figure 15 shows the opticalspectrum for the transmitted signal of the SCM/WDM system model with OFDM technique for eight data streams, where each optical channel consist of four RF channels. As shown from this figure, the eight data streams of bit rate 5 Gbps are modulated into 32-channel RF, which are multiplexed in RF domain. However, in this model, three modulation schemes are utilized, such as: (4-QAM-OFDM, 16-QAM-OFDM and 64-QAM-OFDM), respectively, whereas, these systems have a high ability due to combine the properties of WDM and SCM techniques.

Figure 16 shows SNR versus the length of the optical fiber for SCM/WDM-RoF link with different modulation schemas (4-QAM, 16-QAM and 64-QAM) with OFDM technique at 5 Gb/s bit rate. The signal power equal to the noise power for the SCM/WDM for 4-QAM with OFDM technique after 50 km of fiber length. Moreover, the SNR for this system for 64-QAM with OFDM is higher than the SNR for the SCM/WDM for 16-QAM and 4-QAM with OFDM technique after 60 km of fiber length with other techniques.

The constellation diagram of the 4-QAM with OFDM, 16-QAM with OFDM and 64-QAM with OFDM for SCM/WDM-RoF link for the first and fourth RF channel from third optical channel after 20 km of fiber length is shown in Figure 17.
(i) 4-QAM

(ii) 16-QAM

(iii) 64-QAM

(a) The constellation diagram of the (SCM/WDM)-RoF Link for the channel 1

Figure 17: The constellation diagram of (SCM/WDM)-RoF link for different QAM-OFDM schemes

(ii) 4-QAM

(ii) 16-QAM

(ii) 64-QAM
CONCLUDING REMARKS

The OFDM can be use in optical access networks through combining it with the RoF system, which produces a system with very high efficient communication that uses the bandwidth effectively. Thus, the OFDM-RoF system possess better efficiency compared with the existing communication standards. In other words, by combining the OFDM with the RoF can be created a strong communication standard that uses efficiently the advantages of the optical fiber. In this paper, the performance of the system is improved by combining the properties of WDM and SCM techniques to obtain high data rate with RF channel carried by optical channels through used three modulation schemes, such as; 4-QAM, 16-QAM, and 64-QAM with OFDM technique. The simulation results show that the 16-QAM-OFDM system gives the highest value of the RF signal power and a slight difference of RF signal power with 4-QAM-OFDM. Thus, we can be concluded that the 16-QAM-OFDM system gives the acceptable performance and reduces the complexity of the system which uses a high level of the modulation schemes. However, the outputs waveforms of the analyzer the optical spectrum and the RF spectrum began to broaden and thus decreases the quality when increase the data rate. Similarly, the constellation output also appears an increase in the constellation points.

REFERENCES


