Performance Analysis of the OFDM Scheme for Wireless over Fiber Communication Link

Yoon-Khang Wong, S. M. Idrus, and I. A. Ghani

***Abstract*—Radio over fiber (ROF) has been developed since 20th century and has been used efficiently for the provision of untethered access to broadband wireless communications in a range of applications including last mile solutions, extension of existing radio coverage and capacity, and backhaul. RoF is the next generation communication systems that can utilize the high capacity of optical networks along with the mobility of wireless networks. Optical fiber has many advantages compared to conventional system with low attenuations and superior signal integrity found, it allow much longer intervals of signal transmission. It is not unusual for optical systems to go over 100 kilometers, emerging technologies promise even greater distances in the future. By incorporating OFDM along with RoF, the system can be used for both short distance as well as long-haul transmission at very high data rate. Large capacity RF signals as well as ultra-wide band wireless access is achieved. This paper investigates the performance and characteristics of Orthogonal Frequency Division Multiplexing (OFDM) as a modulation technique for a ROF. The project is about to modeling and simulates OFDM Radio Over Fiber scheme using latest commercial software called Optisystem. This is the pre-exquisite method that only uses standard components of optical telecommunications. As a result the model of this paper can be used with different wireless communication systems such as high data rate Wireless LANs, Fiber-To-Home (FTH), WiMax, and Digital Video Broadcasting (DVB) and it is supporting to the 4th generation cellular systems. The detail of the design in Optisystem and simulated results for the proposed model are shown and elaborate.**

***Index Terms*—OFDM, FTH, ROF, DVB, WiMax.**

I. Introduction

In optical communication nowadays, there is an urgent need to cater the service requirements of ultra-high speed and ultra-large capacity for wireless access network due its spectrum availability, and high-end digital signal processing radio frequency equipments. The current wireless signals suffer from relentless loss along the existing transmission channel as well as free space loss. Research continues to approach the fundamental loss from the unyielding hammering along the current transmission path as well as free space loss suffers by the current wireless signals. In the paper title called “A radio-over-fiber link for OFDM transmission without RF amplification”, the work was about the amplification can be stirred from electrical to optical mode, which allows, for example, having an optical amplifier at the central office and simplifying the base station [1]. With this concept, we apply the optical amplification in the fiber transmission link. By doing so, a better vigorous transmission over fiber is achieved to compromise the minor loss from the fiber. By using optical fibers to transmit radio signal seems to provide promising future for combining wireless and fiber access networks and exhibits a huge potential for the convergent evolution of broadband indoor access network.

The use of radio-over-fiber to provide radio access has a number of advantages including the ability to deploy small, low-cost remote antenna units and ease of upgrade for future potential exploration. For reducing the deployment and maintenance costs of wireless networks while providing low power consumption and large bandwidth, the ROF system seems to be a promising candidate that will make extensive use of many communication standards, such as wireless local area networks (also known as Wi-Fi), digital video and audio broadcasting standards, digital subscriber loop (DSL), and Worldwide Interoperability for Microwave Access (WiMAX, or IEEE 802.16) [2] in order to deliver high bandwidth services to customers. The baseband path for RoF system usually carries the electrical signal as the baseband data, which can be modulated IF signal or the actual modulated RF signal where enhances the sharing of expensive radio equipment located at appropriately sited (e.g. centrally located) Switching Centers (SC) or otherwise known as Central Sites/stations (CS).

Orthogonal frequency division multiplexing (OFDM) is becoming the chosen modulation technique for wireless communications because it can provide large data rates with sufficient robustness to radio channel impairments. OFDM is a transmission scheme uses multiple sub-carriers converts the high rate serial data streams into multiple parallel low rate data streams and hence prolongs the symbol duration, thus helping to eliminate Inter Symbol Interference (ISI) [3] [4]. A single mode or multimode optical fiber is used as a transport mode between the antenna and the base stations where a rack of electronics is located.

On the other hand, Graded Index Polymer Optical Fiber (GIPOF) is promising higher capacity than copper cables, and lower installation and maintenance costs than conventional silica fiber. ROF system converts IF/RF signal to light which is distributed by optical fibers to remote antenna unit (RAU) where it also converts back to IF/RF signal. The light source is the laser modulation which is analog characteristic since the radio-frequency carrier signal is an analog signal. The modulation may occur at the radio signal frequency or at some intermediate frequency if

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frequency conversion is utilized. The resulting optical signal is then carried over the optical fiber link to the receiver station. At the receiving end, the RF signal is demodulated and transmitted to the corresponding wireless user.

By implementing the above technique, ROF technology is able to shift the system complexity away from the remote base station antenna and toward a centralized radio signal processing installation, thereby making it possible to use simpler remote sites. However, optical-to-wireless transceivers in radio-over-fiber (ROF) links have major benefits in improving signal-to-noise ratio and performance transmitted radio frequency (RF) signal.

Taking advantages of both wireless communication and optical communication, OFDM Radio over Fiber (OFDMRoF) system is characterized by high speed, large capacity and high spectral efficiency. This paper will focus in proposing and analyzing the performance of OFDM signal in RoF. We will model and simulate optical OFDM signal utilizing Optisystem software as the main platform using standard optical components which simplified the current design of any wireless network out there.

II. Overview System Design-Principle of Operation

The main idea of this project is to incorporate the OFDM modulation technique into RoF system networks. The chapter also includes of whole the OFDM-RoF system model, and then would explain the system from each part of the transmitter part, the transmission link and the receiver model. At the end of this paper, the design was modeled and simulated for system performance and characteristic analysis. The principle of OFDM is to split high-rate data streams into lower rate streams, which are then transmitted simultaneously over several subcarriers. A multicarrier communication system with orthogonal subcarriers, the carriers spacing is 1/NT, where N is the number of the carriers and 1/T is the overall symbol rate. With this carrier spacing, the sub-channels can maintain the orthogonality, although each sub-channels does experience overlap within the system. Therefore, there is no inter-sub-carrier interference with ideal OFDM systems.

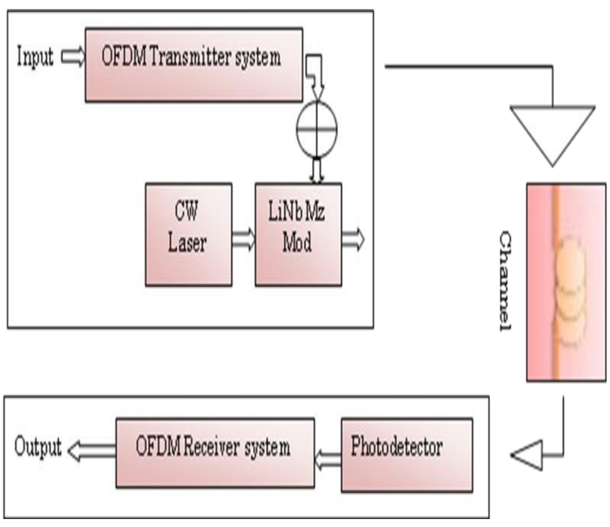

Fig. 1. OFDM-RoF system block diagram.

The OFDM-RoF System design block diagram is shown in Fig. 1. In this project, the optical OFDM system was modeled typically consists of four parts: OFDM transmitter, fiber optic link (single mode fiber), photodetection and OFDM receiver. To generate OFDM orthogonal signal at the base station (BS), it is to sweep the input signal and fed into M-QAM sequence generator and OFDM modulator. In the optical link of LiNb modulator the electrical wave signal from OFDM transmitter are combined with the continuous wave light from CW laser, this two waves are then modulated by LiNb modulator to form the optical signal which is would sent through the optical fiber upon the direction of light propagation. The use of a laser means that multi-gigahertz modulation is possible, and the stimulated light emission is assumed to be directional. Because the laser emitted the light from the surface, single mode or multimode fiber can be directly butt coupled with an inexpensive mounting technology. Length of the fiber for transmission link is from 10 – 50 Km with modulation type 16 QAM/ 4 bit per symbol. By the implementation of the receiver, PIN photodiode is used to directly convert optical power into current (stream of electrons) at the receiver end. The signal then would recombine again in the OFDM receiver to get the original data back.

OFDM system is form using the inverse Fast Fourier transform (IFFT) ensures that data is carried on narrowband sub-carriers in time domain over the channel and is transformed back to frequency-domain using FFT at the receiver. The orthogonality allows for efficient modulator and demodulator implementation using the FFT algorithm on the receiver side, and inverse FFT on the sender side. The total number of sub-carriers translates into the number of points of the IFFT/FFT. OFDM symbol is extended by a ‘cyclic prefix’. Cyclic prefix is a crucial feature of OFDM used to combat the inter-symbol-interference (ISI) and interchannel interference (ICI) introduced by the multi-path channel through which the signal is propagated. The cyclic prefix, which is transmitted during the guard interval, consists of the end of the OFDM symbol copied into the guard interval, and the guard interval is transmitted followed by the OFDM symbol. The reason that the guard interval consists of a copy of the end of the OFDM symbol is so that the receiver will integrate over an integer number of sinusoid cycles for each of the multipath when it performs OFDM demodulation with the FFT.

A. The RoF Transmitter Model Section

In this implementation of the OFDM – RoF transmitter system involves the conversion of one stream of serial data to longer duration parallel data streams, transmitter system were consist of OFDM modulation block system. The data in this design then modulated using 16 QAM/ 4 bit per symbol, then carried by different frequency of each sub carriers which are 4 sub carriers. The OFDM spectrum is centered on fc. An external modulator is also placed between the laser and RF modulated signal due to high modulation efficiency. The outputs of the electro absorption modulator (LiNb) are two sidebands which are located at $\omega 1+ \omega s$ and $\omega 1-\omega s$ where $\omega 1$ and ωs are the radial frequencies.

B. The RoF Link Transmission Model Section

The transmission link is part of implementation of this RoF system network where the signal modulation from OFDM-RoF transmitter would be sent through the optical link before being received by the OFDM receiver. Basically it act as feeder network for up gradation of existing wireless network connects between the transmitter unit and receiver system, which is capable of supporting data rates of the order of Gbps. With RoF is able to shift the system complexity away from the antenna is that optical fiber is an excellent transmission capabilities with low-loss (0.2 dB/km optical loss at 1550 nm).

C. The RoF Receiver Model Section

An exact inverse of the transmitter process is performed at the receiving end. Then the data were received back from the optical link in OFDM demodulation or OFDM receiver part. In this simulation, this receives signals also being gain by the electrical amplifier then demultiplexed back to their own carrier by quadrature and QFDM demodulator obtain the output data.

At first stage of receiving process, according to the square law device photo detection which is electrical power is proportional to i^2 whereby parameter i represent the optical field such as power, complex amplitude; the output of the photodiode will be just the modulated RF carrier and DC level of the output electrical signal. The optical carrier and the other created frequency are canceled out after photo detection operation.

As you can see from the block diagram in the Fig 1, the reception process is straightforward: the received OFDM signal will be filtered to get the corresponding baseband signal and to be sampled in the basic structure of OFDM receiver system. The output of the FFT modulation block is the received constellation. This one passes through a 4QAM slicer, which assigns the received symbols into the four possible constellation points.

III. OFDM-RoF OptiSystem System Model

This particular commercial software transfers the complexity of transmitters and receivers from analog to digital domain. The input data for the OFDM modulator can have different modulation formats: BPSK, QPSK, QAM, etc. The bit data signal at 10Gbps generated by PseudoRandom Bit Sequence Generator connected to the QAM Sequence Generator with 4bits per symbol is connected to two M-ary Pulse Generators.

In this case 16-QAM is used. After the OFDM modulator and quadrature modulator (where the RF signal is up converted to the 7.5 GHz carrier frequency), the generated RF OFDM spectrum is shown in Fig. 2. The signals modulated rightly are tested at the Constellation Visualize and this shows at Fig. 2. The RF OFDM signals then used to drive a LiNb Modulator.

TABLE I: Global Parameter Setup.

Parameter	Value
Bit rate	10 Gbps
Sequence length	1024 bits
Sample per bit	64
Number of samples	65536

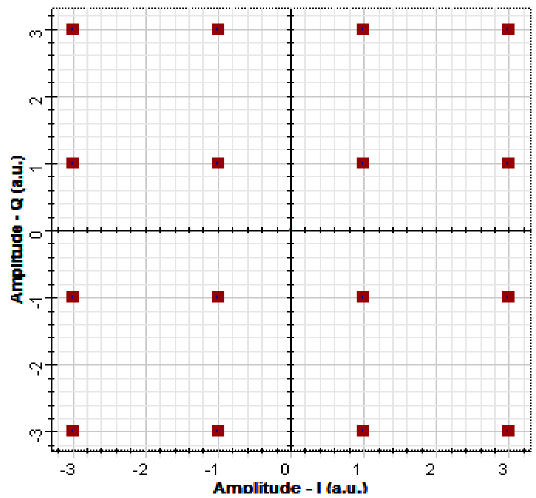

Fig. 2. Constellation of signals 1symbol carried 4 bits.

Before the system modeling is done, a few parameters need to be determined at the layout in OptiSystem. The parameters of the general model in Fig. 2 are summarized in Table I. Various analysis tools are available in OptiSystem library and used in this project to analyze the simulation results. The generation of roburst OFDM-RoF whole system consists of modulator and demodulator using optisystem8.0/9.0 software is shown in Fig. 3.

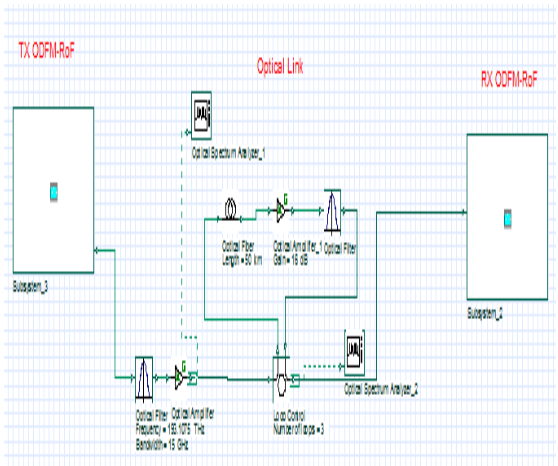

Fig. 3. OFDM-ROF system model develop with optisystem.

IV. Results and Discussion

In this chapter, we present the simulation results from the system design. At this moment, the simulation only considers some important combinations of parameters that dominant in optical data transmission for project simulation purpose. The parameters used in the simulation are some of the values are default values of the optical components itself and hardware specification used in the photonic lab at UTM.

For system performance, baseband signals are analyzed with oscilloscope visualize. Subsequently, RF and optical signals are analyzed with RF spectrum and optical spectrum analyzer, respectively. Meanwhile, recover signal are also study with electrical constellation visualize and eye diagram analyzer can be utilized.

A. Baseband Modulated Result

The result for optical spectrum baseband modulation is presented in Fig. 4 with more harmonics at the sideband of the spectrum. The baseband data rate is set to 10 Gb/s for this case. The resulting for the transmitter part is in electrical domain is portrayed in Fig. 5. Hence the visualizer shows the optical spectrum in which 7.5 GHz has the highest power of approximately -8.5 dBm generated at the output of LiNb MZ modulator.

While for the result shown in Fig. 5 is derived from OFDM signal with 4 sub carriers that have been modulated with M-QAM scheme, channel to OFDM modulator and up converted to 7.5 GHz carrier frequency by quadrature modulator before optically modulated. This electrical signal below will be use to drive the LiNb modulator later on.

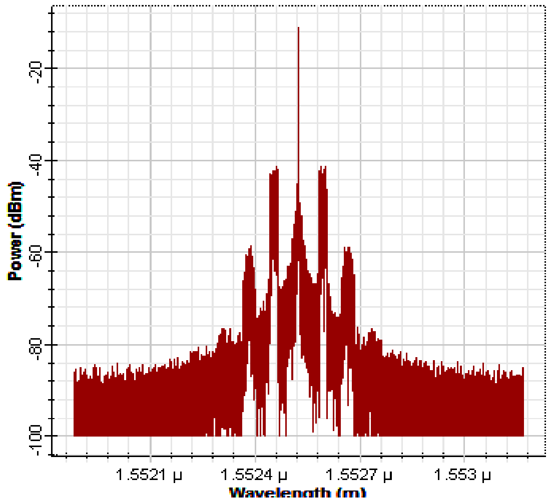

Fig. 4. The optical spectrum of baseband modulation.

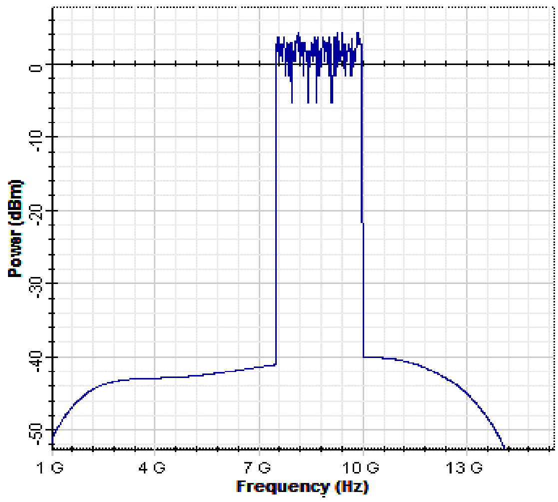

Fig. 5. Transmitter OFDM-ROF signal.

B. *Optically Modulated Result*

In this section we also present the result of both optical signals together with amplification before and after filtering based from the optical transmission link, which is in optical domain as shown in Fig. 6 and. 7. Due to poor spectrum OFDM quality generated over from the baseband and transmission path, therefore enhancement spectrum option is needed through optical amplification.

The performance is mainly hampered by the accumulated amplifier noise, the transmission channel of the system, internal performance system components and etc. The wavelength for CW laser is set to 1550 nm, while the rest are to be set into default value from the Optisystem. The optical fiber attenuation is 0.2dB/km and the fiber length for the transmitting the signals is varied from 10 up to 50 Km. Based on the Fig. 6 and 7 below, we could see that the wavelength is 1550 nm, but the power from both signal are different. The optical modulation of RF carrier produces single sideband signals (after filtering).

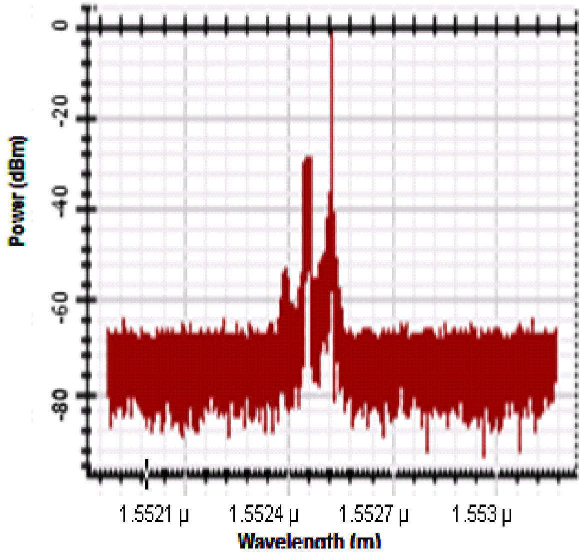

Fig. 6. OFDM signal after through optical fiber (before filtering).

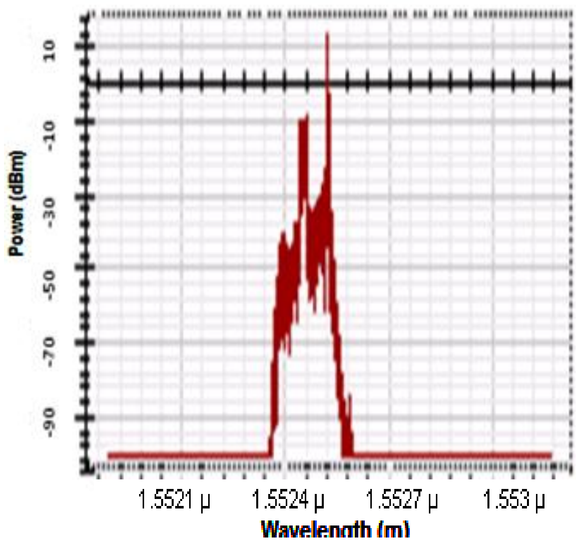

Fig. 7. OFDM signal after through optical fiber (after filtering)

From the output of Optical spectrum analyzer 1 that was generated before the optical signal fed to the single mode fiber, at the carrier of 7.5 GHz show the power of approximately -1 dBm while for the output of Optical spectrum analyzer 2 that was generated after going through the fiber channel carry the power which is higher than optical spectrum analyzer 1 of approximately 5 dBm. From Fig. 7 also referring to optical spectrum analyzer 2 in the design simulation, the signal produces optical signal with fewer harmonic in the sidebands according to the carrier frequency. The carrier remains at 1550 nm but with less power.

V. Conclusion

We presented a whole of the OFDM – RoF system modulator demodulator (MoDem) which transmits QAM-OFDM signal over optical fiber using optical simulation software, Optisystem. The system identification technique has been working with optical and electrical signal processing for performance improvement. Laser light with the frequency of 1550nm carried in 10-50km single mode fiber successfully generate a 7.5GHz RF carrier from RoF system network. The modeling of this proposed method will be useful to help improved the performance quality of the current RF signals wave which will become more useful in today's wireless communication network. The performance of radio over fiber (RoF) system depends on following parameters: method used to generate the optically modulated RF signal, optical fiber channel, laser and RF power level, nonlinearity due to an optical power level, bit rate and modulation format used. However simultaneous use of fiber optic distribution links and optical OFDM signal provide various advantages with in micro cellular systems. The modified wireless communication system with single mode optical fiber as feeder network therefore suggests an excellent cost effective means for transmitting various wide band applications which avoid the complexity of the antenna technology.

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