OFDM MODULATED FULL-DUPEX WDM-ROF SYSTEM

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ABSTRACT

A full-duplex Wavelength Division Multiplexed Radio Over Fiber (WDM-RoF) system is proposed with Orthogonal Frequency Division Multiplexing (OFDM). Electroabsorption modulator, Phase modulator and intensity modulator are cascaded in order to generate a tunable optical frequency comb (OFC). Here, 21 comb lines are generated such that each base station uses three comb-lines. The difficulty in incorporating OFDM into a full-duplex system is overcome by proper design. OFDM signal generated is used to modulate the comb-line in both uplink and downlink transmission. The constellation diagram is plotted for 20 km and 60 km optical fiber. Hence the data can be transmitted over a considerable distance with increased capacity and data rate.

Index Terms: Orthogonal Frequency Division Multiplexing, Optical Frequency Comb, Radio Over Fiber (ROF), Millimeter-Wave (MMW).


1. INTRODUCTION

Orthogonal Frequency Division Multiplexing is a widely used modulation and multiplexing technology, which is now the essence of many telecommunications standards such as wireless local area networks (LANs), digital terrestrial television (DTT) and digital radio broadcasting. In the recent years mobile communication have advanced tremendously from the early analog mobile generation (1G) to the last fifth generation (5G) networks. Photonics technology can play a major role in the emerging fifth generation mobile communication systems. Hence Radio-over-fiber can be implemented in the existing systems[1] and new technologies such as OFDM can be incorporated into such systems in order to increase the spectral efficiency, capacity and data-rate [2][3][4][5].

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Recently, the (RoF) systems are gaining much attraction due to low loss and enormous bandwidth of the optical fiber. Fig. 1 shows the basic block diagram of RoF system. RoF becomes an ideal candidate for realizing microcellular networks due to the benefits it offers in terms of low-cost base station deployment. Hence the increased demand for capacity and coverage can be met. Moreover the 60 GHz MMW is especially attractive for wireless access to future broadband networks and services due to the availability of large amounts of unlicensed radio spectrum[6][7][8].

![Figure 1 Radio-over-fiber block diagram](image)

To fulfill the increasing data transmission capacity, the wavelength-division-multiplexing (WDM) technique has been employed in RoF systems, namely, WDM-RoF. Here, light of different wavelengths are multiplexed onto a single optical fibre, in order to increase the transmission capacity. For WDM-RoF systems, the spectral efficiency is a crucial issue, which considerably determines the transmission capacity of the link.

Therefore, a number of approaches have been proposed to achieve high spectral efficiency. Optical frequency comb is a promising WDM optical source to provide multiple channels for WDM-RoF systems, which can greatly increase the capacity and mobility of RoF networks [9]. Different comb generation techniques exist using mode locked laser and fiber non-linearities. Since these combs lack flatness and stability it cannot be applied to WDM systems. Here, an electro-absorption modulator (EAM), a phase modulator (PM) and a MachZehnder intensity modulator (IM) are cascaded and is driven by an RF signal to generate a tunable Optical Frequency comb at desired frequency [1].

Recently, a unidirectional wireless transmission system using an optical comb with 1 dB power deviation was proposed [4]. To meet the ever-increasing demands in future communication systems, bidirectional fiber-optic transmission in RoF link is a promising solution. There are various methods being proposed to realize the bidirectional transmission in RoF links [10]. The existing schemes systems are required to have a multiple side-mode injection-locked DFB Laser Diodes that should be wavelength selected for each channel and controlled to operate at specific wavelengths. But this scheme is not feasible in terms of cost and complexity of the system [11], [12].

In this paper a full duplex WDM-RoF system is deployed with OFDM modulation scheme. Here an Optical Frequency Comb is first designed with improved flatness and stability using an Electro-absorption Modulator, Phase Modulator and an Intensity Modulator. 10 Gbps data is OFDM modulated and is used for transmission in both uplink and downlink. The signal constellations are obtained after proper reception of the signal. This paper is organized as follows. In Section II Optical frequency comb generation is explained. Section III gives the detailed description of the full duplex WDM-OFDM-RoF system design. The simulation results are shown in Section IV. Finally the conclusions are presented in Section V.

The modulated electrical signal can be expressed as

\[ I_{RF}(t) = V_{RF} \cos(\omega_{RF}t) \]  

1
2. TUNABLE OPTICAL FREQUENCY COMB GENERATION

Fig. 2 shows the schematic diagram of the OFC generator, which consists of a continuous-wave laser at 193.1 THz, an RF source, EAM, PM and an IM [1]. A sinusoidal RF driving signal with the frequency of 10 GHz is applied to drive the cascaded EAM, PM and IM. The Phase Modulator is used to generate OFC with a number of frequency lines which improves the tunability of the generated OFC, while the Intensity Modulator is used to flatten the spectrum of the generated OFC [1]. An optical band-pass filter (BPF) is used to choose comb lines for use.

Hence, the flat comb lines generated by the tunable OFC generator have advantages of low complexity, high stability where \( V_{RF} \) is the electrical signal amplitude, \( \omega = 2\pi f_{RF} \) is the angular frequency of RF. A Laser diode is used to generate a signal at 193.1 THz as shown in Fig. 3(a). Then signals are coupled into an EAM. Fig. 3(b) shows the output spectra of EAM with 10 GHz spacing. The RF signal is boosted in an electrical amplifier (EA) and is used to drive PM and IM to an optimized level.

After the EAM modulation, Phase modulation is done which generates a number of comb lines. Then these comb lines are sent into a MachZehnder IM to make further flatness. The output spectra of IM is shown in Fig. 3(c). Thereby, the flatness can be improved up to 0.2 dB. Then a Band-Pass Filter is used to filter the 21 comb lines as shown in Fig. 3(d) and is transmitted to the 7 Base Stations.
3. SYSTEM DESIGN

A WDM-OFDM-RoF cellular network is considered where to each central station there exist 7 base stations. From each station millimeter wave is transmitted through the antenna to the end user. The schematic block diagram of the full-duplex OFDM modulated system is shown in Fig. 4. The selected 21 comb lines at the center frequency of 193.1 THz with 0.2 dB flatness is injected into a circulator and an FBG. The bandwidth of the FBG is 0.04 nm and the center frequency is 193.1 THz. FBG is used to choose different comb line. The reflected carrier is modulated with the OFDM signal.

![Block diagram full-duplex WDM-OFDM-RoF system and good tunability.](image)

A Pseudo random sequence generator is used to generate a PN sequence at a data rate of 10 Gbps. This Pseudo Random Sequence is then QAM modulated. Here 16-QAM sequence is generated. The symbols generated from the QAM generator is then OFDM modulated and then given to the Quadrature Modulator to combine both in-phase and quadrature components. The OFDM spectrum generated is shown in Fig. 5(a). The OFDM signal when modulated with 193.14 THz light beam, generates a spectrum as shown in Fig. 5(b). The OFDM modulated signal is then combined with the remaining comb lines before they are transmitted through fiber. A 1:7 splitter For the downlink, an arrayed waveguide grating (AWG) is utilized to filter out the signals on different comb lines. Based on the AWG, the carrier with downlink signal beats with one of the comb lines and generates the MMW.

![RF spectrum of (a) OFDM signal (b) OFDM modulated with 193.14 THz signal (c) Photo detector output (d) OFDM demodulated signal in down link is used to separate 7 parts corresponding to each cellular network.](image)
The beating of the band modulated with downlink signal with the comb line generate different MMWs (Fig. 5(c)). We assume that one comb line is selected from left and one from right of the modulated comb line. The left and the right region can be written as

\[ E_L(t) = A \cos[(\omega_0 + 2.\pi.\Delta f.i)t + \phi_0], -n \leq i \leq -1 \]  \hspace{1cm} (2)

\[ E_R(t) = A \cos[(\omega_0 + 2.\pi.\Delta f.j)t + \phi_0], 1 \leq j \leq n \]  \hspace{1cm} (3)

where A is the amplitude of the comb line generated by the proposed OFC generator, 2n is the total comb line index, \( \phi_0 \) is phase and \( \Delta f = 10\text{GHz} \) is the frequency interval of the OFC. At the receiver, two comb lines are selected and is detected using a PIN diode and the output current of the PIN can be described as

\[ I(t) = R. |E_L(t) + E_R(t)|^2 \]  \hspace{1cm} (4)

where R is the responsivity of the PIN. The frequency range of the MMW is \([10, 2n\Delta f]\) GHz with a frequency spacing of 10 GHz. For, \( j - i = 4, 6, 8 \) three common MMWs with frequencies of 40 GHz, 60 GHz and 80 GHz are obtained.

**Figure 6** RF spectrum of (a) OFDM signal (b) OFDM modulated with 193.1 THz signal (c) Transmitted SSB signal (d) OFDM demodulated signal in uplink

This electrical signal at 60 GHz is then amplified by an Electrical Amplifier and is radiated by an antenna for wireless transmission. Then at the receiver an OFDM demodulator is used to down-convert the electrical mm-wave signal to baseband signal. The spectrum of the OFDM demodulated signal is shown in Fig. 5 (d).

For the uplink, one of the combline allocated for uplink in each base station is selected and modulated with 10 Gbps 16- QAM OFDM modulated data signal. After transmission over some length of SMF, a low frequency Avalanche photo-diode (APD) is used to detect the baseband wired signal directly and is then OFDM demodulated to recover the data. The output spectrum of OFDM, OFDM modulated signal, SSB transmitted signal and OFDM demodulated signal in uplink is shown in Fig. 6 (a), (b), (c) and (d) respectively.
4. SIMULATION AND RESULT
The system was simulated using Optisystem 14 software. A bi-directional system is designed with OFDM modulation.

A. Simulation Results
The above system was implemented for both uplink and downlink transmission for 16-QAM-OFDM modulated data. Table I shows the parameters used for comb generation.

The OFDM signal is generated with the parameters mentioned in Table II. The OFDM signal is generated at a central frequency of 5 GHz and is used to modulate the data in both uplink and downlink. The signal is transmitted through the fiber for 20 km and 60 km transmission and the various stages of transmission and reception is explained in the previous Sections. Fig. 7 (a) and (b) shows constellation for 20km and 60km fiber transmission for downlink. Fig. 7 (c) and (d) shows constellation for 20 km and 60 km fiber transmission for uplink. The constellation diagram shows that the system performs well for a 16-QAM OFDM system for both uplink and downlink.

![Constellation Diagrams](image)

**Figure 7** Constellation diagram of (a) 20 km downlink (b) 60 km downlink (c) 20 km uplink (d) 60 km uplink

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
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<tr>
<td>Laser Diode Frequency</td>
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<tr>
<td>RF Signal Frequency</td>
<td>10 GHz</td>
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**Table I COMB Generation Parameters**

<table>
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<th>OFDM Parameters</th>
<th>Value</th>
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<tr>
<td>No. of sub-carriers</td>
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<tr>
<td>No. of FFT points</td>
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</tr>
<tr>
<td>Data-rate</td>
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</table>

**Table OFDM Design Parameters**
5. CONCLUSION
A full-duplex WDM-OFDM-RoF system is designed. OFDM introduced into the system considerably increases the spectral efficiency as data can be transmitted full-duplex to 7 base stations using 200 GHz bandwidth. OFC is generated with greater stability and flatness. 60 GHz millimeter wave is generated for wireless transmission which can achieve capacities as high as 10 Gbps full duplex, which is unlikely to be matched by any lower frequency RF wireless technologies. Bi-directional OFDM signals are successfully transmitted with good performance in both uplink and downlink. 16-QAM-OFDM modulation is performed and the constellation diagrams are obtained for both downlink and uplink at 20 km and 60 km fiber length transmission. The key contributions are high data rate and higher spectral efficiency which significantly improves the system performance.

REFERENCES

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