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Design and Evaluation of a Hybrid 2D-SWZCC OCMDA System with Multicarrier MM-Wave

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Abstract. *This paper presents a hybrid communication system combining optical code division multiple access (OCDMA) and multicarrier millimeter-wave (MM-Wave) architecture operating at 35, 55, 75, and 95 GHz connected to a home network center (HNC) and the end user (EU). Hybrid Link reduces congestion on complex RF networks by combining optical fiber backhaul with radio links. The OptiSystem simulation demonstrates successful data transmission and transmission capacity at 40 Gbps over various distances. Furthermore, this new 40G-MM wave OCDMA system that takes advantage of a two-dimensional single-weighted zero cross-correlation (2D-SWZCC) system with a multiplexing scheme of polarization wavelength multiplies the same N channels to M OCDMA code of the MM-Wave system that dramatically increased scalability. The comparative analysis shows that the proposed 2D-SWZCC hybrid algorithm outperforms 1D-SWZCC regarding scalability. This study contributes to developing communication algorithms with high data rates and provides promising solutions for method limitations and scalability in hybrid-MM-Wave-OCDMA architectures.*

Keywords: *millimeter-wave (MM-Wave), optical code division multiple access (OCDMA), and two-dimensional single-weighted zero cross-correlation (2D-SWZCC).*

1. INTRODUCTION

The increasing demand for high-speed and high-capacity communication schemes has expanded advanced technologies such as hybrid optical code division multiple access systems (OCMDA) with 4-channel multicarrier millimeter wave (MM-Wave) speeds. The capabilities of such systems include a 2D-SWZCC scheme with polarization and wavelength multiplexing to improve its reliability. This paper aims to develop and test a hybrid scheme using OCDMA, focusing on components and design considerations, supporting a 2D-SWZCC design regarding system performance, practical advantages of polarization, and wavelength multiplexing. Some discussion through a comprehensive review of relevant literature and analytical analysis. This paper aims to provide insights into the potential advantages and limitations of a hybrid OCMDA system with 4-channel multicarrier MM waveforms for high-speed and high-capacity communication protocols.

Achieving beamforming in a hybrid OCDMA system requires the combination of both the RF analog domain and the baseband digital domain [1]. The RF analog domain antenna uses phase shift to control the antenna element of the subarray. In contrast, the baseband digital domain uses a channel matrix to determine communication loads and pre-coding, a trade-off between flexibility, measuring features such as power allocation, and analog precoding design [1], [2]. In addition, the system incorporates a hybrid connector, which focuses on maximizing the overall system rating [2], [3]. The optimal scheme is chosen based on the differences in each subchannel, and the optimal analog precoding is approximately obtained by considering the continuous feasibility of each sub-matrix [2]. Analog-hybrid precoders in hybrid precoding schemes, BD technology, and MU-MIMO systems include electrical power distribution employing water filling [2]. The system has been solved in analog precoding and digital precoding, where BD technology optimizes digital precoding under uniform processes to eliminate inter-user interference [2]. The design of the analog hybrid precoder is optimized to maximize the benefits of all analog beamforming, between ware complexity and system performance. To obtain a suitable interval, the receiver function may be modified as an asymmetric receiver for future applications [2].

In millimeter wave systems, hybrid beam fabrication has emerged as a cost-effective transceiver solution [4]. Several studies have proposed different hybrid beam design structures to achieve greater hardware efficiency than existing ones [5]. This paper presents a new multi-beam non-orthogonal multi-access systems design for hybrid millimeter wave (MM wave) systems and explores the advantages of incorporating the 2D-SWZCC system. Also, [6] studies MM wave for hybrid precoding in large MU-MIMO systems, considers the integrated structure, and evaluates the system performance by incorporating the 2D-SWZCC framework. The proposed scheme significantly increases the transmission rate and reduces the loss of multiple paths, improving the system performance [2][7]. This paper also addresses the design of a hybrid beamforming system considering the circuit parameters of a six-bit millimeter wave phase shifter. This design finds the functional variations and adverse effects of phase shifts and provides a better understanding of the effects on system performance control [1][7]. Different digital pre-coding techniques have been proposed [8]. This study emphasizes the importance of hybrid beam construction and additional systems to achieve optimal performance in millimeter wave systems.

In hybrid millimeter wave systems, polarization and wavelength multiplexing offer many advantages. Hybrid beamforming structures have been proposed as a cost-effective solution for MM wave systems, which can reduce implementation costs and energy consumption [4][9]. Hybrid beamforming structures are one such type, and six-bits have been proposed recently. Millimeter wave phase shifters, which are more hardware efficient than existing structures, were able to reduce multipath fading [5][1] significantly. In addition to inter-beam interference (IBI) in MM wave cellular systems, hybrid beamforming is among them. To reduce it, researchers have proposed digital pre-coding techniques [8]. In a recent paper, the authors propose a multi-beam non-orthogonal multiple access (NOMA) scheme for hybrid MM-wave systems, which transmit to numerous users simultaneously in the same frequency band and improve spectral efficiency [6]. Furthermore, double lens schemes in OFDM-FSO systems have been shown to significantly increase the transmission rate and reduce multipath fading [10]. Nevertheless, polarization and wavelength multiplexing increase spectral efficiency and improve message quality in a hybrid MM-wave system.

The design and analysis of the hybrid OCMDA system with 4-channel multicarrier MM-Wave incorporating the 2D-SWZCC system with polarization and wavelength multiplexing [11]. The study highlights the importance of combining the RF analog and baseband digital domains to achieve beamforming in a hybrid OCDMA system. Using a six-bit millimeter wave phase shifter based on a process design kit is a cost-effective solution in designing hybrid beamforming systems. Analog Hybrid Precoder, BD Technology, for MU-MIMO systems by wetting in for power and distribution are included in the hybrid precoding process. The study results show that polarization and wavelength multiplexing enhance the spectral efficiency of hybrid MM wave systems and provide improved transmission characteristics. However, the study acknowledges that the proposed system has limitations, such as complex phase shifter design. Hence, there is a need for further optimization of the digital pre-coding algorithm so that future research can focus on algorithm a more efficient development for digital precoding. Contributes to the continuous improvement of knowledge and provides an avenue for further research on hybrid OCDMA systems.

The hybrid system proposed in this paper combines optical code division multiple access with multicarrier millimeter-wave architecture. This integration addresses the channel limitations and scalability challenges of millimeter-wave communications for high data rates and spectral efficiency 35 to 95 GHz MM-Wave frequencies provide the bandwidth necessary for fast data. Still, their range and limitation in its interference sensitivity lead to difficulties that must achieve communication OCDMA technology reliable and effective; in particular, two-dimensional weighted zero cross-correlation (2D-SWZCC) code is included. Using 2D-SWZCC code in a hybrid system can enable multiple OCDMA codes in the same MM-Wave system to create various channels to increase scalability and user capabilities. The system architecture includes optical fiber backhaul connectivity from the home network hub to the user end, enabling optical and radio channels to be combined to reduce congestion at dense RF access points.

2. OCDMA SYSTEM DESIGN

In SAC OCDMA [12, 13], the conventional SAC-OCDMA coding, MAI, and associated intense noise (IN) simultaneously limit the user interface's performance above the ground. The 1D OCDMA-based design requires more extensive code lengths and weights, which increase the associated MAI and IN, which affect the system performance [12-15], but the 1D SAC-OCDMA code length, broadband the bandwidth of familiar sources is constrained in SAC-OCDMA systems [13-16]. These incoherent optical sources require high chip width in encoders and consume considerable bandwidth to accommodate receivers. Shorter lengths and better cross-correlation coding schemes are needed to support the higher capacity of receivers and transferred data. To address the network scalability limitations of 1D-OCDMA, the Balanced Incomplete Block Design (BIBD) algorithm is used to formulate the 2D-OCDMA framework, 1D ZCC [17], for hybrid systems. The number of users (H) analyzed depends on the length (K) and weight (W) of the code, as defined by the equation the following explains [11].

$$H + (W - 1) \times H \leq K \qquad (1)$$

$$H \leq \frac{K}{W} \qquad (2)$$

The weight code (W=1) used in SWZCC forces the number of users, H, to be equal to or less than the code length K. In developing 1D-SWZCC, it starts in the identity matrix (M × M). immediately,

$$I_2 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad (3)$$

The second step is to generate new matrices (a_2) by replacing row $I_{\sqrt{K}}$ of the first matrix with one. Then, the process is repeated to compute for a_3 by changing the series of a_2 by one, and so on. This progression is repeated until all N matrices (a_N) are created, where N is M. Now apply Equation 4 to a_k (k=1,2,3,…, N) matrices:

$$a_1 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} , \ a_2 = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

$$b_k(i + (j - 1) \times N, j) = a_k(i, j) \qquad (4)$$

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$$b_1 = \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix} \quad , \; b_2 = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix}$$

The matrixes b_k will be combined to form these SWZCC codes.

$$SWZCC = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

The 1D-SWZCC coding method to generate 2D-SWZCC is applied to the 2D system, combining polarization and wavelength (P/W). The method doubles the number of possible users, mainly when two polarization states are used even through that spectral signature, as shown in Equation (5). In this study, two polarization axes are set at 0° and 90° using a polarization beam splitter [18].

$$\boldsymbol{H_{2D} = 2 \times H_{1D}} \quad \textbf{(5)}$$

3. SYSTEM DESIGN

The proposed design of four groups of residence buildings, each with four homes, shown in Figure 1, consists of three stages: transmitter, link, and receiver. In the transmitter, the data of each user are generated by a pseudo-random generator and encoded by a non-return to zero (NRZ) pulse generator. Then, the signal will be modulated by an AM modulator with a specific frequency for each MM-wave channel. A power combiner will multiplex the signals of those MM waves. Then, they will be optically modulated by a Mach-Zehnder modulator, which will convert the light wave generated by the light source. The light source consists of two laser diodes with different wavelengths and different polarization to achieve that 2D OCMDA code, as illustrated in Figure 2.

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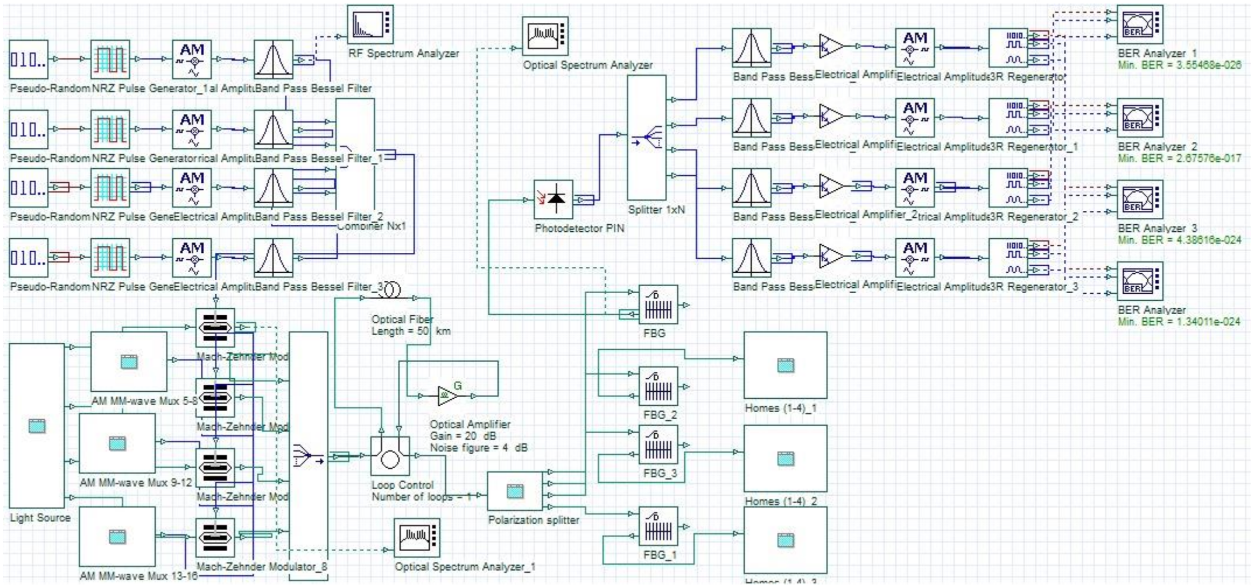

Fig. 1. The block diagram of the proposed system.

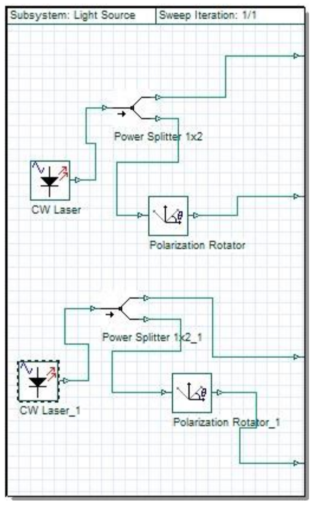

Fig. 2. The light source of the proposed system.

The channel concerns a standard single-mood fiber and optical amplifier to compensate for the effect of optical fiber attenuation. A polarization splitter will handle the two polarization signals, shown in Figure 3, to separate the light signal and then direct each signal to a particular group. A fiber brag grating FBG with a dispersion compensation will be used to decode the OCMDA on the receiving side, and an MM-wave AM demodulator will recuperate the data.

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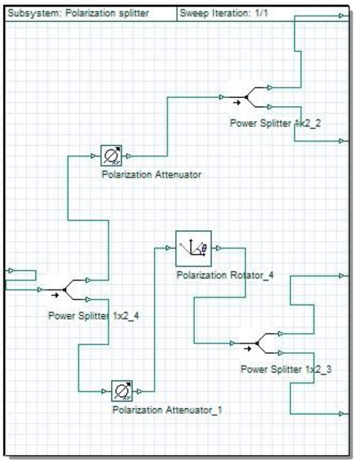


Fig. 3. The polarization splitter of the proposed system.

4. RESULTS AND DISCUSSION

The proposed hybrid system of OCDMA (2D-SWZCC) with four channels of multicarrier MM-wave was evaluated for performance in terms of quality and capacity. Figure 4 shows the relationship between the Q-factor and various optical fiber distances of the proposed system with a source power of 0 dBm, and the carrier channels are 35, 55, 75, and 95 GHz, respectively, in the first residence group. Furthermore, Figure 5 shows the eye diagrams of those four channels at a distance of 50 km of optical fiber, where the eye-opening clarifies the noise level and time jitter in each received signal.

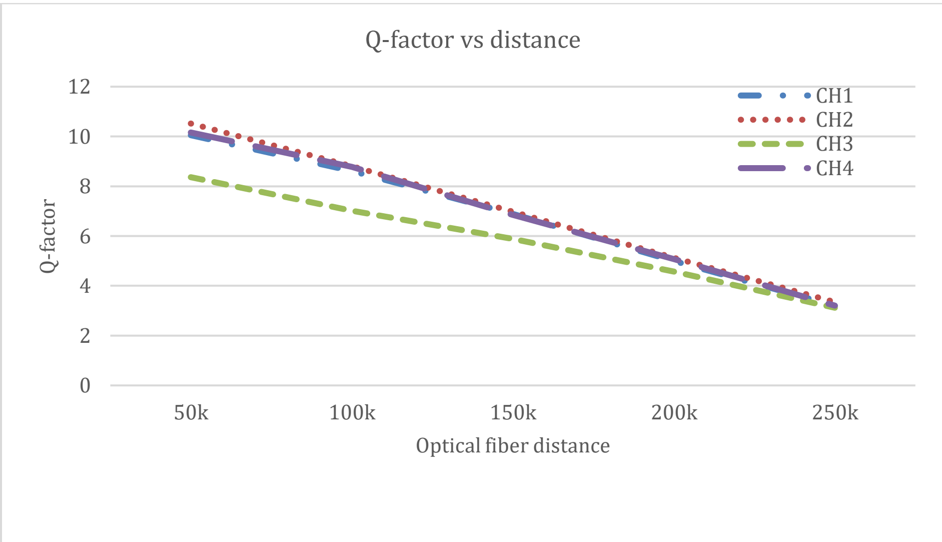
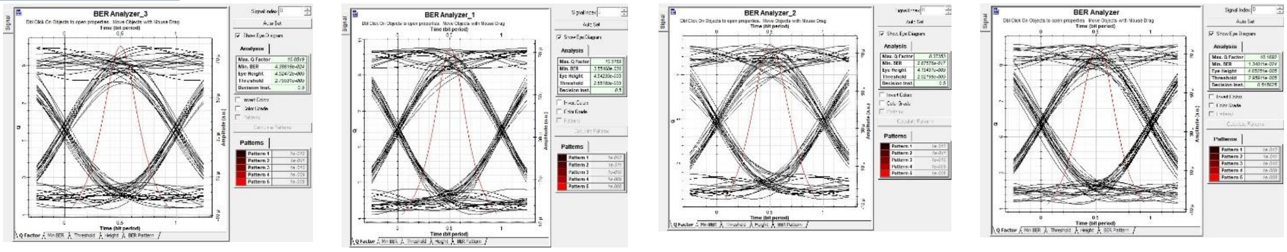


Fig. 4. The Q-factor vs the optical fiber distance of the proposed system with a source power of 0 dBm.



CH1 CH2 CH3 CH4

Fig. 5. The eye diagrams of four multicarrier MM-wave in the first residence group.

The results showed that the system achieved high data rates and provided reliable communication for long-reach optical links while obtaining a significant increase in scalability. Furthermore, it has been demonstrated that the proposed system significantly reduces the interference generated by multiple access and improves the system performance compared to the traditional OCDMA system.

5. CONCLUSION

The 2D-SWZCC-OCDMA hybrid scheme with four multi-band millimeter channels performed successfully, obtaining good quality and higher capacity. The system demonstrated reliable connectivity for large distances of optical fiber links at high data rates. Furthermore, the proposed scheme can reduce the number of multiple access interferences and improve the overall performance compared to conventional OCDMA. The proposed scheme uses a hybrid approach that combines OCMDA and multicarrier MM-wave technologies in this research to enhance the spectral efficiency and ability of optical communication networks while monitoring improved lower energy consumption, which results in better resource utilization. According to this study, the hybrid 2D-SWZCC-OCDMA system with four multi-band MM channels represents a viable solution for high-speed and high-performance communication systems.

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