4 × 4 MIMO Fiber-Wireless System with RoF Transmission Capability

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Abstract. Transport networks, particularly fronthaul systems are facing substantial issues as a result of the expansion of radio access technologies (RATs) in 5G and beyond networks. Due to the difficulties and high expense of installing fiber links, a traditional fiber-optic based mobile transport system will not be adequate for delivering radio signals to new antenna sites. The ease and speed of installation make wireless transport systems an appealing alternative. In this work, a 4×4 MIMO fiber wireless system with wavelength division multiplexing (WDM) and polarisation division multiplexing (PDM) radio over fiber (RoF) transmission capacity is proposed and Simulated. Moreover, a Filter Bank Multicarrier modulation is employed to increase the system capacity. In order to improve the spectral efficiency of RoF and fiber-wireless systems, FBMC is an excellent choice for modulation. Also a 4×4 MIMO OQAM based FBMC signal is simulated and its performance is compared with 2 × 2 MIMO system. Satisfactory performance is confirmed with quality factor of 14.6040 and minimum BER of 1.22×10^{-45}. 4 × 4 MIMO fiber wireless system achieved better quality factor compared to 2×2 MIMO system. Simulation of both systems are performed using Matlab integrated with Optisystem Software. It offers an affordable solution to enable massive amount of MIMO signal transmission and may be a potential approach for upcoming mobile access and radio transport networks in high frequency bands.

1 Introduction

Online services have become an essential part of modern life due to outstanding developement of mobile technology and internet. As a result, many people try to access a wide range of data through the use of their gadgets or mobiles wherever and whenever they are, irrespective of whether the network is operating normally or otherwise. However, including in networking devices, optical fiber communication invention can currently only consolidate a significant quantity of data flow [1]. Moreover, due to a number of restrictions such geographic location, Strong links based on optical fibre, such as fibre to the residence, are not always established everywhere due to financial stability, supplier plan, and harm situation in the case of calamities. Therefore it has been desired that two physical characteristics of both

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wired and wireless connection [2]. Because it may allow for smooth and straight approach to the photonic circuit, a strong radio connection similar to photonic fiber is need for interaction. Moreover, the optical fibre network will be shielded against fibre cutting by the network connected elevated radio channel technology. Millimeter wave (MMW) wireless is a viable competitor for a high-speed radio connection built on a radio-over-fiber technology since straight and smoother conversion is possible with this approach, particularly with a direct optoelectronic up translation technique. The application of high bandwidth and diversification in sophisticated radio transmission also depends on MIMO technology.

MIMO fiber-wireless systems in high-frequency bands have been the subject of several investigations [3]–[12]. Recently, MIMO radio signal transmission networks using wavelengthdivision multiplexing (WDM) and intermediate frequencyover- fiber (IFoF) have been developed [3]–[6]. The technology looks exciting since it is adaptable for massive amounts MIMO signals and easy to generate many IFoF impulses. However, because electrical signal up-conversion is used, the antenna location is difficult. Electrical mixers and signal- to-signal beat interference also have an impact on the system. Fiber-wireless systems that utilise radio-over-fiber (RoF) should be taken into consideration for situations that only need basic antennas [7]–[12]. However, due to the usage of optical polarizationdivision multiplexing (PDM) RoF systems in earlier investigations, the size of MIMO signals was constrained to 2×2 in size. A 3×3 complete MIMO fiber-wireless system with radio-over-fiber (RoF) and wavelength-division multiplexing (WDM) and polarization-division multiplexing (PDM) transmission capabilities was recently demonstrated [13]. Using the optical heterodyne approach, it is difficult to implement a complete MIMO fiber wireless network with MIMO sizes greater than 2×2. This is due to an interference between radio waves, which causes highly difficult signal synchronisation and demodulation due to the fast and independent variations in the frequency of the carrier and phase noise.

In this paper, a 4×4 MIMO system with both PDM and WDM RoF transmission capability is proposed. Also to increase the system capacity, high spectral efficiency FBMC modulation is used. The simulation of both the systems are performed using Matlab integrated with Optisystem software and compared the performance of both the system. In this paper, section 2 describes the Concept of Filter Bank Multicarrier Modulation, section 3 presents the block diagram of 2×2 MIMO fiber wireless system and 4×4 MIMO fiber wireless system, section 4 gives the simulation results and finally the conclusion in section 5.

2 Concept of Filter Bank Multicarrier

Filter Bank Multicarrier (FBMC) modulation is a type of multicarrier modulation scheme that is designed to overcome some of the limitations of traditional multicarrier schemes such as Orthogonal Frequency Division Multiplexing (OFDM). In FBMC, instead of using a rectangular pulse shape for each subcarrier as in OFDM, a filter bank is used to shape the spectrum of each subcarrier.

FBMC uses a set of prototype filters, also called subband filters, to divide the input signal into multiple subbands, which are then modulated using various modulation schemes. The subband filters are carefully designed to avoid overlap between adjacent subbands, which helps to mitigate the effects of inter-symbol interference (ISI) and inter-carrier interference (ICI).

One advantage of FBMC over OFDM is that it can achieve a higher spectral efficiency by using a more efficient use of the available bandwidth. This is because the subband filters can be designed to have a smaller transition band, which allows for a more compact spectral representation of the signal. FBMC also has a better time-frequency localization than OFDM, which makes it more resistant to frequency-selective fading and interference.

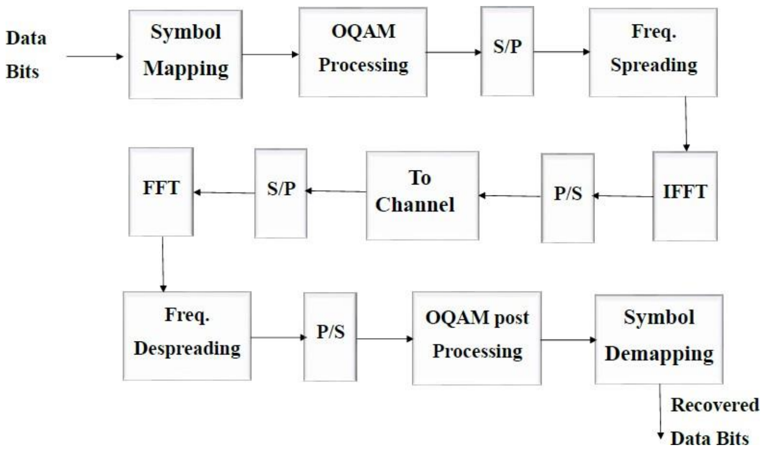

Figure 1. Block Diagram of Filter Bank Multicarrier Modulation

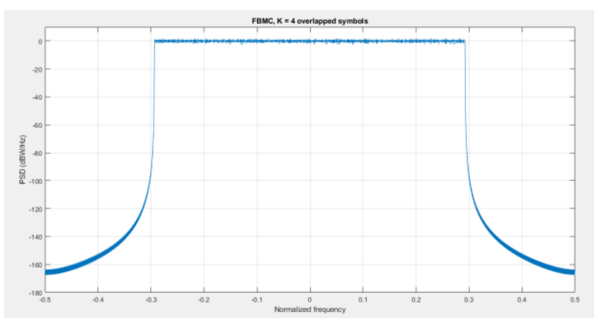

Figure 2. FBMC, K=4 overlapped symbol

The fig.2 shows waveform of Filter Bank Multicarrier Modulation. In this system, no. of FFT points are set to 1024, Guard bands on both sides are set to 212, overlapping symbol are selected by 4, Simulation length in symbols are set to 100 and SNR in dB are set to 12dB.

3 System Analysis

3.1 4×4 MIMO fiber wireless system

The block diagram of 4×4 MIMO fiber wireless system using both PDM and WDM RoF transmission is shown in Fig 3. To develop a 4×4 MIMO wave transmission, the system uses 4 WDM channels for signal generation and transmission. Two tone signal generator generate two optical signals and the side bands of the generated signal had a frequency separation of 79.6 GHz. The generated signals are of different wavelength to make it as a WDM RoF system. The one of the side band of optical signal is modulated using FBMC signal with

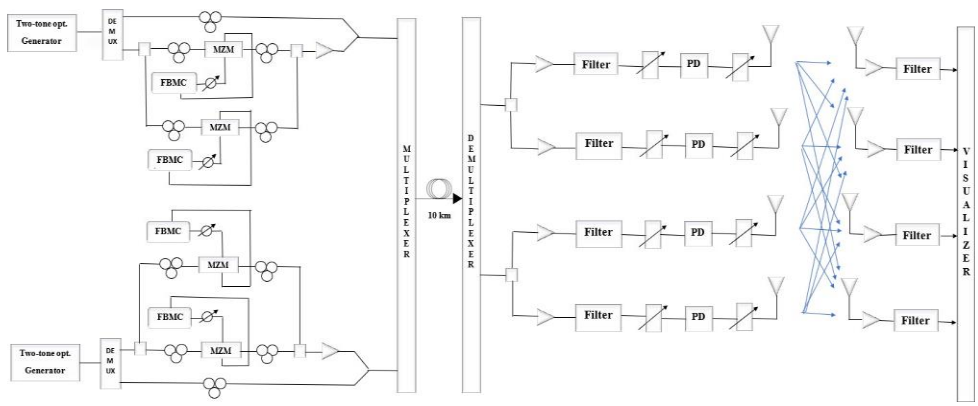

Figure 3. Block Diagram of 4×4 MIMO system with RoF transmission

frequency of 8 GHz. The other side band is kept unmodulated for a reference signal. To make PDM transmission, the modulated side band was separated using polarization splitter. The separated polarization signals were modulated by two different FBMC signal. The output of the MZ modulator was RoF signals. Then these polarization signals are combined by using polarization combiner. Then it is amplified by optical amplifier and combined with unmodulated reference signal. This process is applicable for other optical signal.

The combined RoF signals were multiplexed and transmitted through single mode fiber with distance of 10km. At the receiver side the transmitted signal was demultiplexed and split by using polarization splitter to make as a PDM system[15]. The separated waves are amplified by optical amplifier and filtered to reduce the amplified spontaneous emission. Then it is fed into attenuator and given to the photo detector. Photo detector convert these optical signals into electrical signals, then transmit it into free space using four transmitter antennas. The antenna transmission is simulated on MATLAB and integrated into Optisystem software using MATLAB component. Also the antenna reception was simulated by this process. Generated radio signal had the frequency of 87.6 GHz which were formed by optical signal with 79.6 GHz and side band modulation with 8 GHz.

The free space transmission over approximately 1 meter distance were done by using horn antennas. The adjacent antennas are separated approximately 10 cm. The spacing was selected owing to the separation required to place the receiver antenna[16]. The received signals are amplified by low noise amplifier and filtration was performed using low pass filter. And it is visualized by RF spectrum analyzer and generated the eye diagrams.

To develop a MIMO signal transmission, we produce a 4×4 MIMO OQAM FBMC wave in MATLAB. By using PDM and WDM, we can increase the size of the MIMO system and can increase the system capacity. A greater degree of spectrum efficiency is demonstrated by FBMC, which makes significantly better use of the existing channel capacity and may provide larger data rates within an allocated radio spectrum bandwidth. This system can generate better signal compared to 2×2 MIMO system because of both the PDM and WDM RoF transmission.

3.2 2×2 MIMO fiber wireless system

The block diagram of 2×2 MIMO fibre wireless system using a WDM RoF transmission is shown in Fig 4. The optical millimeter signals are produced by using two tone generator. The side bands of millimeter signals are separated by 79.6 GHz. To make optical signal as a WDM RoF signal, they are generated at different wavelengths. Compared to 4×4 MIMO system, in this system only uses WDM transmission. So size of the system was limited to 2×2. In each optical wave, the side bands of optical signals are separated and one of them is modulated by FBMC wave signal with frequency of 8GHz. Other side band of optical signal is kept unmodulated to work as a reference wave. This process is also applicable on other optical signal[18]. The remaining process are similar to 4×4 MIMO system.

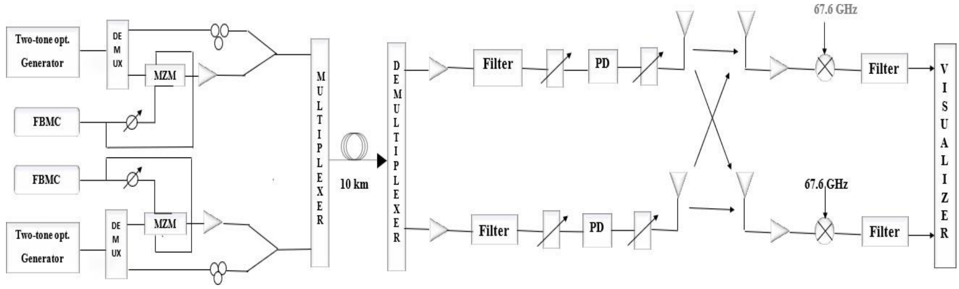

Figure 4. Block Diagram of 2×2 MIMO system with RoF transmission

4 Simulation Results

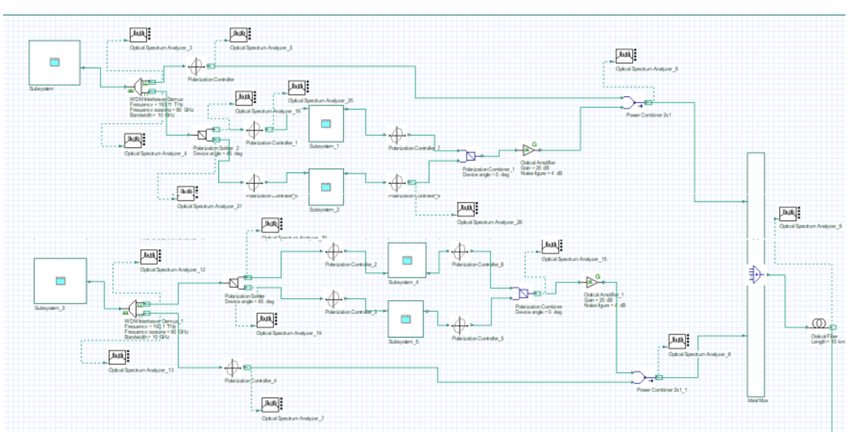

Figure 5. Simulation block diagram of 4×4 MIMO Fiber section

The Figure 5 shows the simulation block diagram of 4×4 MIMO fiber section. In this section subsystem 1 and 3 represent the two tone generator. In this subsystem CW laser,

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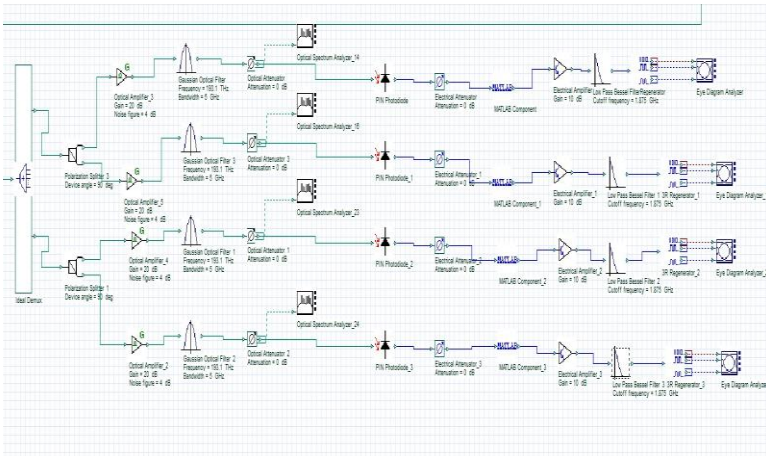

Figure 6. Simulation block diagram of 4×4 MIMO Wireless section

MZ modulator, NRZ are used to generate two optical millimeter wave signal with frequency separation of 79.6 GHz. The subsystem 1,2,4 and 5 represents the modulation section. In this section FBMC signal generated offline in MATLAB and downloaded it into MATLAB component[19].

The Figure 6 shows the simulation block diagram of 4x4 MIMO wireless section. This section include transmission and reception of MIMO signal through 4 transmitter and 4 receiver antennas[20]. The received signal from fiber are demultiplexed and separated using polarization splitter and amplified using optical amplifier, then it is fed to gaussian filter to reduce the amplified spontaneous emission noise, then transmitted through antennas.

Figure 7 shows the signal generated from the fiber and signal received by antenna which had a frequency of 87.5 GHz. Then these signal were amplified by using electrical amplifier. These signal was down coverted to desired frequency using low pass filter by setting the frequency which is required as output frequency.

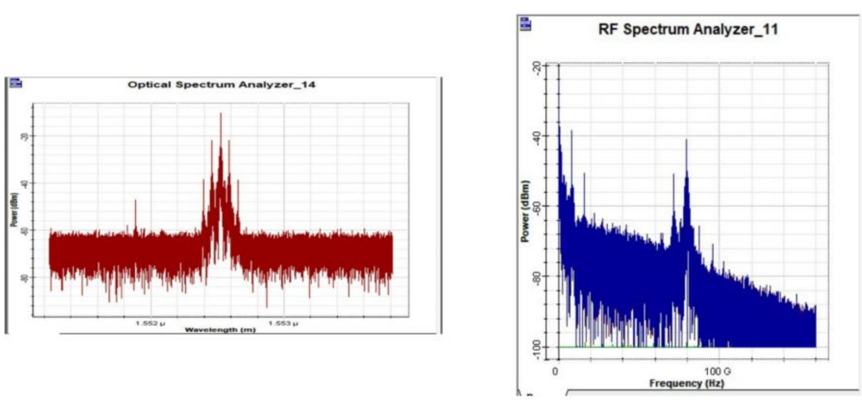

Figure 7. (a) Signal generated from the fiber (b) Signal received by the antenna

Table 1. Quality factors received by the antennas

Antenna Number	Quality factor
Antenna 1	14.8037
Antenna 2	14.7669
Antenna 3	14.7776
Antenna 4	14.0679

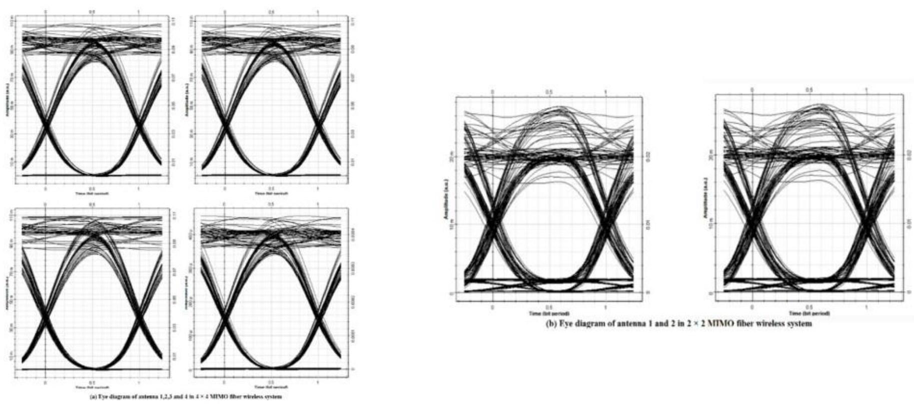

Figure 8. Eye diagram of antenna in 4 × 4 and 2 × 2 MIMO fiber wireless system

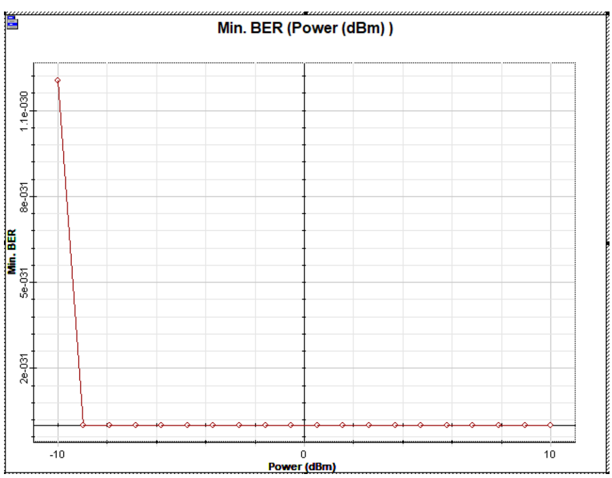

Figure 9. BER performance of 4×4 MIMO fiber wireless system

The 2×2 MIMO fiber wireless system provide a quality factor of 6.1773 and minimum BER of 2.59×10^{-10}. Figure 9 shows the BER performance of 4×4 MIMO system. The 4×4 multiple input multiple output fiber wireless system provide a quality factor of 14.6040 and minimum BER of 1.22×10^{-45} which is double of 2×2 MIMO fiber wireless system. Compared to 2×2 MIMO fiber wireless system, this system achieved better quality factor.

Table 2. Quality factors received by the antennas in 2 × 2 MIMO fiber wireless system

Antenna Number	Quality factor
Antenna 1	6.1539
Antenna 2	6.2008

5 Conclusion

In this paper, a 4×4 full multiple input multiple output fiber wireless system with RoF transmission capability is proposed and simulated. We employed a OQAM FBMC modulation to increase the system capacity. This modulation perform better usage of the available channel capacity, it means higher level spectrum efficiency. In order to increase the size of the MIMO system, both PDM WDM RoF transmission were used. Satisfactory performance was confirmed with quality factor of 14.6040 and minimum BER of 1.22×10^{-45}. This system is applicable for large MIMO wave transmission by using both PDM and WDM RoF channel. This system provides high capacity transmission in high frequency band. If size of the system increases with combined RoF capability will results better performance in future.

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