# COFDM for Radio over Multimode Fiber: a Review

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## ABSTRACT
This paper presents a review on COFDM technique to combat transmission impairments for radio over fibre. COFDM is multicarrier modulation where its carrier spacing is carefully selected so that each subcarrier is orthogonal to the other subcarriers. In multimode fibres the effect of COFDM on modal dispersion is selected as material dispersion is very small compared to modal dispersion.

## Keywords
Radio over fibre, COFDM, Multimode fibre

## 1. INTRODUCTION
There are several optical techniques for generating and transporting microwave signals over optical fiber. The RoF techniques may be classified into three categories – (i) RF-over-fiber (RFoF) (ii) IFover- Fiber (IFoF) and (iii) baseband-over-Fiber (BBoF) [1]. RFoF involves the transmission of the actual RF signal over the fiber. Therefore, depending on the transmission method used, the RAU may be more complex or simpler. RoF techniques may also be classified in terms of the underlying modulation/detection principles employed. In that case, the techniques may be grouped into three categories: (i) intensity modulation – direct detection (IMDD) (ii) remote heterodyne detection (RHD) and (iii) harmonic up-conversion techniques. RFoF or simply RoF systems fall under the IM-DD category. IFoF and BBoF systems, which involve the use of a LO at the RAU may also employ IM-DD to transmit the baseband data or IF to the RAU. In most cases, IFoF and BBoF schemes rely on RHD for RF signal generation.

Particularly, radio over multimode fiber system (ROMMF) has gained much attention recently for its suitability to deliver high-purity signals in analogue and digital format for short-reach coverage such as wireless local area networks and ultrawideband radio signals [2]. Since OFDM is widely used today in many applications, it is one of the preferable modulation schemes for next-generation systems. In ROF, OFDM impact has been demonstrated with multimode fiber (MMF) as a promising modulation scheme for mitigating the modal dispersion penalty [3]. OFDM is inherently able to transfer a frequency-selective fading channel into a number of flat fading sub-channels. However, inserting cyclic prefix between sub-carriers relaxes the intersymbol interference that can destroy the orthogonality among sub-carriers. This is achieved by setting the carrier spacing and reciprocal of the symbol period to be equal [5]. By implementing coding and interleaving across sub-carriers, the effect of multipath fading is minimized since interleaving reorganizes the number of bits in a way so as to avoid the effects of fading. Convolutional coding is being used commonly in OFDM systems, and it can give coding gain at different coding rates [4, 6]. Thus, coded-OFDM (COFDM) makes the transmitted signal robust to multipath fading and distortion. MMF has a merit of being used for short-distance applications; it is typically a popular choice for in-building networks. MMF possesses a large core diameter (>50 mm) leading to better coupling efficiency with an optical source. In addition, it is cheaper than single-mode fiber (SMF) since it has lower installation and maintenance costs. Thus, a wide selection of services with different signal characteristics such as fast ethernet, gbit ethernet, video, audio and control signals are likely to be supported by MMF within a range of a few kilometers. As a low-cost route, MMF is an attractive and cost-effective solution for transporting multiple services. However, the signal propagation through MMF is subject to significant signal impairment leading to both attenuation and time spread of the transmitted signal. The latter is caused basically by material dispersion and modal dispersion. Dispersion causes pulse broadening as the pulse propagates along the fiber which limits the information carrying capacity of an optical fiber, and is determined by bandwidth–distance product which typically is measured in (MHz km). In contrast to SMF, modal dispersion exists in MMF because of the large number of fiber modes being propagated inside the core of MMF.

## 2. BASIC PRINCIPLES OF COFDM [7]
Coded OFDM (COFDM) is one of the widely used transmission techniques for overcoming the frequency selectivity of the channel. The basic idea of coded OFDM is to encode input data and interleave the coded symbols. The interleaved symbols are split into several sub channels to achieve frequency diversity. Even though the unencoded symbol error rate is high for the subcarriers with low channel gains, with the channel coding and interleaving it is possible to correct the errors in the low gain channels. With the channel coding and interleaving, coded OFDM provides a robust communication link for many wireless channel environments. This technique is very effective for channels with narrow coherence bandwidth. However, if the coherence bandwidth is large, then the channel gains of neighbouring sub channels are highly correlated and this may limit the diversity gain of coded OFDM systems.

- Sub-carrier orthogonality can be viewed in two ways, namely the time, and the frequency domains. In the time domain, each sub-carrier must have an integer number of cycles during each OFDM symbol interval (duration). In other words, the number of cycles between adjacent subcarriers differs by exactly one as shown in Figure 1.a in the frequency domain, the amplitude spectra of individual sub-carriers (which are PSK or QAM modulated) overlap as shown in Figure 1.b However, at the maximum of each subcarrier spectrum, all other sub-carrier spectra are zero. Since the OFDM receiver calculates the spectrum values at the maximum points of individual subcarriers, it can recover each sub-carrier without ICI interference from other subcarriers.

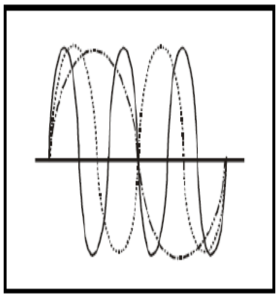

**Figure 1(a) OFDM Symbol with Three Orthogonal Sub-carriers in one.**

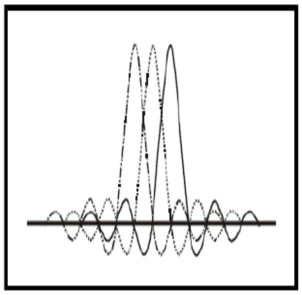

**Figure 1(b) OFDM Symbol with Spectra of Three OFDM Sub-carriers**

- Use staggered QAM to increase the efficiency of band usage. In this way the individual spectra of the modulated carriers still use an excess bandwidth of a, but they are overlapped at the 3-dB frequency. The advantage is that the composite spectrum is flat. The separability or orthogonality is achieved by staggering the data (offset the data by half a symbol). The requirement for filter design is less critical than that for the first scheme.

- Use the discrete Fourier transform (DFT) to modulate and demodulate parallel data. The individual spectra are now sinc functions and are not bandlimited. The FDM is achieved, not by bandpass filtering, but by baseband processing. Using this method, both transmitter and receiver can be implemented using efficient FFT techniques which reduce the number of operations from N2 in DFT down to about NlogN. As is well known, orthogonal signals can be separated at the receiver by correlation techniques; hence, intersymbol interference among channels can be eliminated. This can be achieved by carefully selecting carrier spacing, such as letting the carrier spacing equal to the reciprocal of the useful symbol period. OFDM can be simply defined as a form of multicarrier modulation where its carrier spacing is carefully selected so that each subcarrier is orthogonal to the other subcarriers.

- An example of a coded OFDM system is the 802.11a Wireless Local Area Network (W-LAN) system in the 5GHz band [10]. The IEEE 802.11a standard uses a coded OFDM scheme which demultiplexes coded symbols into 52 separate subcarriers. Data rates of the 802.11a system are 6, 9, 12, 18, 24, 36 and 48 Mbps. Data rates below 24 Mbps are mandatory. Coded data symbols are transmitted over 48 subcarriers. The remaining 4 subcarriers are used as pilot subcarriers. A pseudo-random sequence is transmitted through the pilot subcarriers to avoid spectral lines. The receiver knows the signal sent on the pilot subcarriers and uses the pilot subcarriers for channel estimation. For channel coding, a convolutional code with constraint length k = 7 and rate 1/2 is used. A rate 3/4 code is made by puncturing a coded symbol among three symbols. In the time domain, a guard period is inserted between two OFDM symbols to prevent overlapping of two consecutive symbols by multipath delay spread.

## 3. MULTIMODE FIBERS

Although single mode fibre comes with high performance and much less pulse spread, it is both expensive and fragile. For a network-wide usage it will increase the cost to unreasonably high levels (still more than 99.5 per cent of all fibres deployed in the U.S. are multi-mode fibres). Multimode fibres are cheap, easy to handle and widely deployed in the field. There are mainly two important kinds of dispersion mechanisms in fibres: material and modal dispersion [9].

### 3.1 Material Dispersion

The index of refraction of a material is dependent on the wavelength, so each frequency component of light actually travels at a slightly different speed. As the distance increases, the pulse becomes broader, resulting material dispersion. In multimode fibres, material dispersion is very small compared to modal dispersion, so we will neglect this effect in our work.

### 3.2 Modal Dispersion

There are mainly two types of multimode fibres: step index and graded-core index. The graded core index is the second generation optical fibres, developed for cancelling most of the pulse spread with gradually changing the core index of the fibre according to a profile. In [11] the minimum modal dispersion of MMF occurs at the optimum α. As the modal dispersion is minimum at αopt, the largest achievable 3-dB bandwidth can be obtained at αopt. It was noted that α controls the profile shape of the refractive index. When α= 2, the core profile exhibits a parabolic shape. Nevertheless, by increasing α, the core profile becomes gradually uniform and converges to the step-index (SI) profile for large values of α (α›› 25).

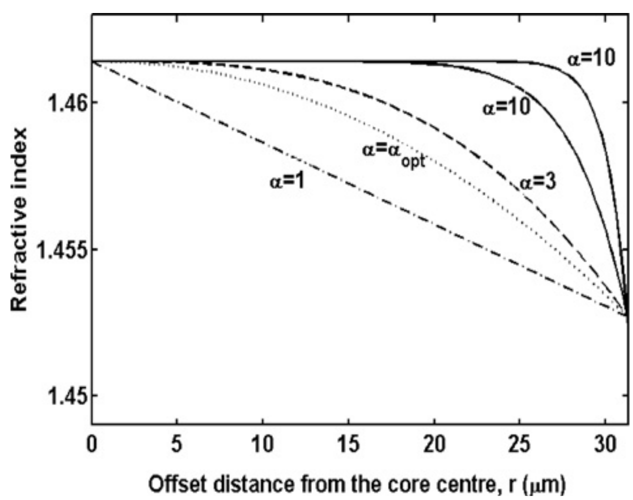


**Fig. 2 Refractive index profile for 62.5/125 mm MMF, n1=1.46143, n2=1.45274, D=0.00595 and λ= 850 nm**

From results of [11] taking the BER= 10^-5, the required Eb/N0 is 8.12 dB. However, as shown in the fig. 3 small deviation from αopt (αopt + 5%) increases the Eb/N0 to 10.21 dB which results in 2.09 dB penalty to achieve the same BER. Moreover, further deviation from αopt (αopt + 10%) necessitates the Eb/N0 to be around 11.63 dB. Thus, additional penalty by 1.42 dB will be induced to maintain the same BER. As a result, the effect of modal dispersion is considerably reduced by tailoring of the refractive index profile of the fibre. However, the only disadvantage is that it is more expensive than SI-MMF.

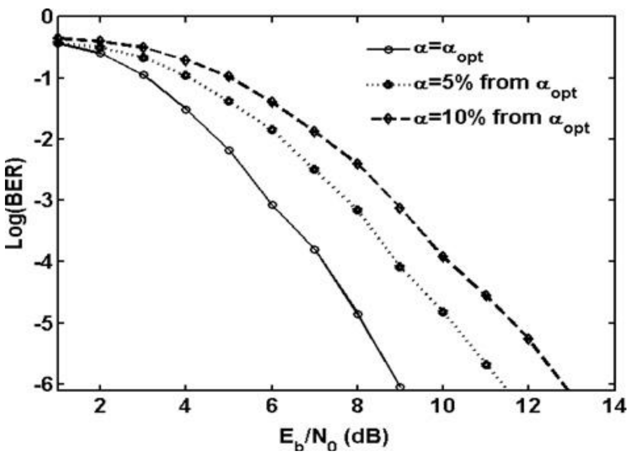


**Fig. 3 Deviation from αopt**

The BER is improved when using softbit weighting jointly with LLR in the viterbi decoder. For α = 1, around 1.6 dB gain is achieved at BER of 10^-5 compared with the conventional metric (MLR) used in softviterbi decoder, whereas for α= 3 and α=10, the improvement is ~2.5 and ~3 dB, respectively.

[11] Shows that increasing the length of MMF degrades the system performance even though with efficient use of COFDM owing to dispersion and losses. However, for short-distance applications, COFDM can be used efficiently for high data rate signal delivery and to tolerate the effect of modal dispersion. Also, the exponent refractive index profile effect has been studied and shown that the best performance can be achieved near the optimum value of exponent refractive index profile.

Tolga Kurt, Abbas Yongacoglu, concluded in [10] as long as the fibre length is reasonable, multimode fibres, even step index multimode fibres can be used for ROF systems. For those systems, the dispersion is compensated by the cyclic prefix. With the cyclic prefix, we ideally expect no performance penalty until the point where multipath delay spread plus multimode fibre dispersion exceed the cyclic prefix duration. The delay spread increases, resulting from either an increase in the fibre length or an increase of α parameter of the fibre, are compensated by the cyclic prefix up until some point. That point is reached when the total wireless delay spread plus the optical delay spread is equal to the cyclic prefix duration. After that point performance loss occurs.

## 4. PROJECT METHODOLOGY TO BE FOLLWED

As shown in fig. 5, first the methodology starts with literature study and review on the RoF system and COFDM modulation technique. Then understanding the modelling design of COFDM modulation technique for RoF system. After this will follow theoretical analysis of COFDM and RoF system.

Model the system and analyze characterization of the system modelled. The COFDM-RoF system will be modelled and simulated using commercial software, which is Optisystem 4.0 from Optiwave.

Next is analyzing the result and system performance which is obtained from the simulation model. While analyzing the result, the system will be optimize to get a better performance and best simulation result. This would be done with referring to the theoretical and numerical analysis part again to double check whether some part is missing.

Finally after all the simulation shall be done and all the result derived, compare the result with previous work and theoretical analysis.

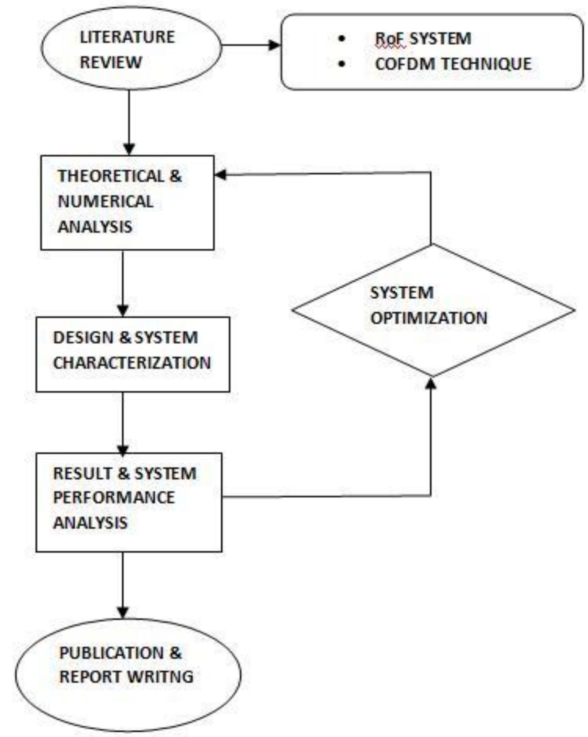


**Fig.5 Flow chart showing project methodology**

## 5. CONCLUSION

OFDM/COFDM has been long studied and implemented to combat transmission channel impairments. Its applications have been extended from high frequency radio communications to telephone networks, digital audio broadcasting and digital television terrestrial broadcasting. The advantages of COFDM, especially in the multipath propagation, interference and fading environment, make the technology a promising alternative in digital communications including terrestrial television broadcasting. Current research and development of COFDM around the world will certainly provide us with valuable findings in theory and implementation.

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