UNIVERSITY OF CALCUTTA

Institute of Radiophysics and Electronics

Mini Project- 6^{th} Semester
How OFDM signal can be designed to solve:
1. Frequency selective fading
2. Mitigation of Inter-symbol interference (ISI)
3. Circular convolution problem in transmission

August 13, 2021

Shirshendu Chatterjee
T91/ECE/184068

Abstract

Orthogonal Frequency Division Multiplexing (OFDM) is the multiple access technology for Fourth Generation (4G) communications. Due to its resilience to multipath fading and support for high data rates at minimal complexity, it has an edge over other technologies like Code Division Multiple Access (CDMA) and Time Division Multiplexing Access (TDMA). A wireless channel is characterized by multi-path propagation leading to Frequency Selective Fading. Inter-symbol interference (ISI) is a sort of deformation of a sign. In ISI one symbol interferes with following symbols has similar effect as noise, therefore fixing the communication less consistent. The presence of ISI in the system introduces errors at the receiver output. In this report we use OFDM as a solution towards fading thus encountering ISI. At the channel output, the output being received as a linear convolution is made as circular convolution using cyclic prefix and thus mitigating ISI. The block diagram of OFDM signal generation and its transmission and receiving sections are clearly demonstrated.

Acknowledgements

I would like to earnestly acknowledge the sincere efforts and valuable time given by my Project teacher **Prof. Abhirup Das Barman**, our HoD **Prof. Abhijit Biswas** and our coordinator **Prof. Kaushik Mandal**, for giving me this wonderful opportunity to work on this exciting topic. Their valuable guidance and feedback helped me in completing this project.
Also, I would like to mention the support system and consideration of my parents who have always been there in my life.
Last but not the least, my fellow project partners **Nilotpal Chatterjee**, **Anish Das** and **Nishant Kumar**, without whom completion of this project would not have been possible.

Shirshendu Chatterjee, 6^{th} Semester
T91/ECE/184068

Introduction

In the present age of ever-growing industry and to keep up with these rapid strides of technological advancements, it is important to keep developing newer technological aspects and upgrade existing ones through research and experiments in each and every aspect of the technological domain. Communication systems, principles and theory are no exception to this. It forms the backbone of the technology industry. As a result, it needs constant modification, needs tech researchers to come up with new and more sophisticated ideas in order to support all the other industries in their respective fields. The utmost need of the present modern age can be described in a single word as: speed. Be it looking for a new mobile phone or a washing machine, people demand faster machines, systems that are able to perform their tasks super-fast but not compromising the efficiency simultaneously. This trade off between speed and efficiency plays a major role while designing newer technologies and has to be perfectly balanced so as neither of them is sacrificed completely. One of the fundamental aspects of communication theory being the Data Rate. If we want to design faster machines, we need to design machines that are able to communicate at incredibly fast rates. This effectively implies that we need to step up our data rate, and keep increasing it with time. But we can not simply go on increasing this data rate, which like every other thing comes at a cost as well. This poses a major obstacle in our goal of reaching higher and higher data rates. With this fundamental goal of achieving faster data rate and how to combat the issues that are encountered, I propose the following research question:

Design of OFDM Signals for solving:
1. Frequency selective fading
2. Mitigation of Inter-symbol interference (ISI)
3. Circular convolution problem in transmission

What is OFDM?

OFDM is a form of multicarrier modulation. An OFDM signal consists of a number of closely spaced modulated carriers. When modulation of any form - voice, data, etc. is applied to a carrier, then sidebands spread out either side. It is necessary for a receiver to be able to receive the whole signal to be able to successfully demodulate the data. As a result when signals are transmitted close to one another they must be spaced so that the receiver can separate them using a filter and there must be a guard band between them. This is not the case with OFDM. Although the sidebands from each carrier overlap, they can still be received without the interference that might be expected because they are orthogonal to each another. This is achieved by having the carrier spacing equal to the reciprocal of the symbol period.

To see how OFDM works, it is necessary to look at the receiver. This acts as a bank of demodulators, translating each carrier down to DC. The resulting signal is integrated over the symbol period to regenerate the data from that carrier. The same demodulator also demodulates the other carriers. As the carrier spacing equal to the reciprocal of the symbol period means that they will have a whole number of cycles in the symbol period and their contribution will sum to zero - in other words there is no interference contribution.

One requirement of the OFDM transmitting and receiving systems is that they must be linear. Any non-linearity will cause interference between the carriers as a result of inter-modulation distortion. This will introduce unwanted signals that would cause interference and impair the orthogonality of the transmission.

In terms of the equipment to be used the high peak to average ratio of multi-carrier systems such as OFDM requires the RF final amplifier on the output of the transmitter to be able to handle the peaks whilst the average power is much lower and this leads to inefficiency. In some systems the peaks are limited. Although this introduces distortion that results in a higher level of data errors, the system can rely on the error correction to remove them.

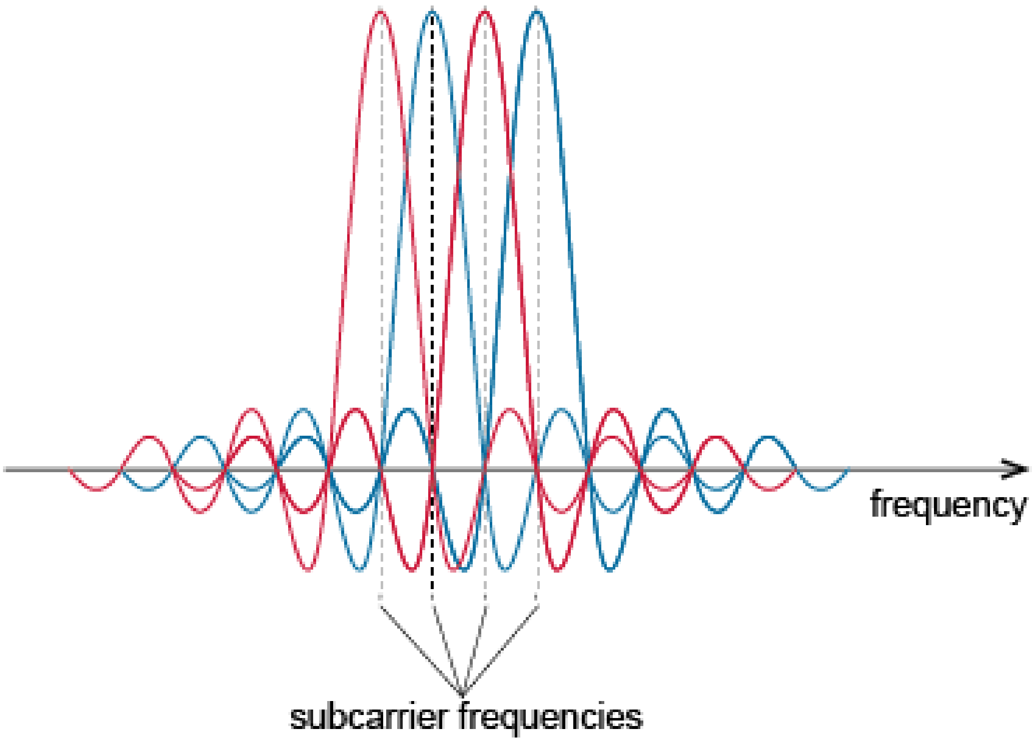

Figure 1

OFDM advantages disadvantages

OFDM advantages

OFDM has been used in many high data rate wireless systems because of the many advantages it provides.

- **Immunity to selective fading:** One of the main advantages of OFDM is that is more resistant to frequency selective fading than single carrier systems because it divides the overall channel into multiple narrowband signals that are affected individually as flat fading sub-channels.
- **Resilience to interference:** Interference appearing on a channel may be bandwidth limited and in this way will not affect all the sub-channels. This means that not all the data is lost.
- **Spectrum efficiency:** Using close-spaced overlapping sub-carriers, a significant OFDM advantage is that it makes efficient use of the available spectrum.
- **Resilient to ISI:** Another advantage of OFDM is that it is very resilient to inter-symbol and inter-frame interference. This results from the low data rate on each of the sub-channels.
- **Resilient to narrow-band effects:** Using adequate channel coding and interleaving it is possible to recover symbols lost due to the frequency selectivity of the channel and narrow band interference. Not all the data is lost.

- **Simpler channel equalisation:** One of the issues with CDMA systems was the complexity of the channel equalisation which had to be applied across the whole channel. An advantage of OFDM is that using multiple sub-channels, the channel equalization becomes much simpler.

OFDM disadvantages

Whilst OFDM has been widely used, there are still a few disadvantages to its use which need to be addressed when considering its use.

- **High peak to average power ratio:** An OFDM signal has a noise like amplitude variation and has a relatively high large dynamic range, or peak to average power ratio. This impacts the RF amplifier efficiency as the amplifiers need to be linear and accommodate the large amplitude variations and these factors mean the amplifier cannot operate with a high efficiency level.

- **Sensitive to carrier offset and drift:** Another disadvantage of OFDM is that is sensitive to carrier frequency offset and drift. Single carrier systems are less sensitive.

Key features of OFDM

The OFDM scheme differs from traditional FDM in the following interrelated ways:

- Multiple carriers (called subcarriers) carry the information stream.

- The subcarriers are orthogonal to each other.

- A guard interval is added to each symbol to minimize the channel delay spread and intersymbol interference.

Frequency selective fading

In wireless communications, fading is variation of the attenuation of a signal with various variables. These variables include time, geographical position, and radio frequency. Fading is often modeled as a random process. Selective fading or frequency selective fading is a radio propagation anomaly caused by partial cancellation of a radio signal by itself — the signal arrives at the receiver by two different paths, and at least one of the paths is changing (lengthening or shortening). This typically happens in the early evening or early morning as the various layers in the ionosphere move, separate, and combine. The two paths can both be skywave or one be groundwave.

Frequency selective fading occurs when the symbol length is shorter than the delay spread, or equivalently when signal bandwidth is larger than the channel bandwidth. It is therefore the type of multipath interference encountered by high bandwidth, high data rate signals in outdoor areas where excess delays are relatively long. A consequence of frequency selective fading is intersymbol interference where symbols received over the direct or the shortest reflecting paths are interfered with by previous symbols arriving at the same time over longer delay paths.

As the carrier frequency of a signal is varied, the magnitude of the change in amplitude will vary. The coherence bandwidth measures the separation in frequency after which two signals will experience uncorrelated fading.

In frequency-selective fading, the coherence bandwidth of the channel is smaller than the bandwidth of the signal. Different frequency components of the signal therefore experience uncorrelated fading.

Frequency-selective fading channels are also dispersive, in that the signal energy associated with each symbol is spread out in time. This causes transmitted symbols that are adjacent in time to interfere with each other. Equalizers are often deployed in such channels to compensate for the effects of the Inter-symbol Interference(ISI).

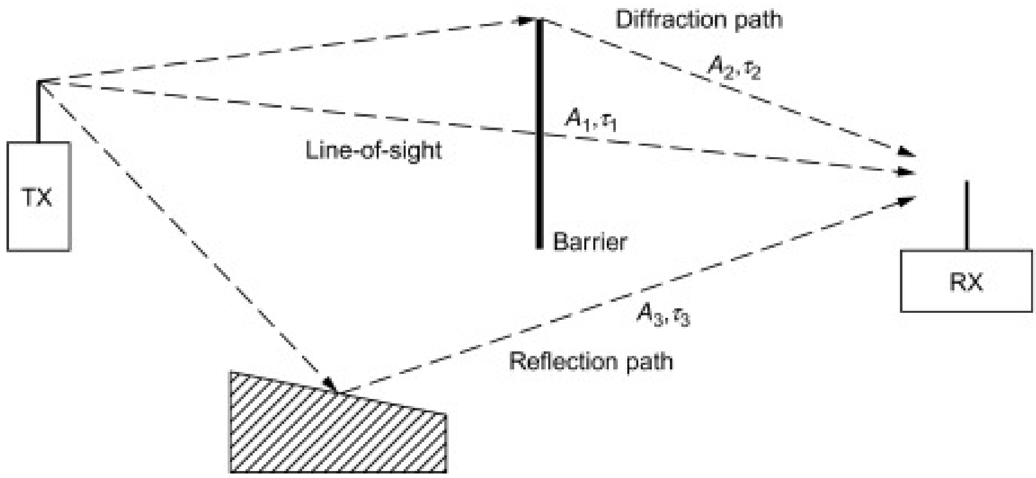

Figure 2

Let us assume, our data is being transmitted to a distant location through a unguided medium (air) which is full of obstacles. Digital data which is being transmitted are nothing but sampled sequences of our original analog message signal. Let the sampling interval be Ts. If we further assume the transmitter, is ideal i.e. isotropic and omni-directional in nature, then at the receiver end we tend to receive a number of delayed versions or echoes of the original data impulse in decreasing order of magnitude. The reason being that the transmitted data impulse suffers reflection due to obstacles in the medium, covers a larger distance, fades out in magnitude and arrives late at the receiver. The first or earliest impulse arriving at the receiver is that impulse which suffered the least amount of reflection or which has travelled the shortest path between the two points. This phenomenon is known as Frequency Selective Fading and is a serious challenge faced in practical scenarios for efficient and interference-less communication.

Solution

To retrieve the originally transmitted data out of the several delayed and faded out impulses, the best option would be to allow only the earliest impulse which most closely resembles the original transmitted impulse and reject all its delayed versions. But the complicacy arises when we send streams of impulses representing our data bits, continuously at regular intervals. The delayed version of a previous impulse may arrive at the receiver at the same instant when the next impulse arrives. Thus, the impulses or bits tend to interfere with each other which makes it very difficult to communicate in a distortion less and noise free manner. The echo signals tend to die out gradually and after some time the effect of that echo signal on interference becomes negligible and can be ignored. For this reason there exists a quantity called the Channel Bandwidth BC which says that, the transmitted signal bandwidth B should be less than the channel bandwidth for interference-less data communication i.e.

$$B \leqslant B_c, \text{ where } T_m = \frac{1}{B_c} \text{ is the delay spread}$$

As long as the bit rate is within this limit, the delayed impulses do not interfere with the successive impulses and as a result no inter symbol interference (ISI) is encountered. This channel bandwidth is a fixed quantity which depends on the nature of the concerned medium and not changeable by us. Hence it imposes a restriction on the maximum bandwidth which is achievable for efficient data communication. This acts a limitation against the need for ever increasing bandwidth or faster data rates.

What is ISI?

In telecommunication, inter-symbol interference (ISI) is a form of distortion of a signal in which one symbol interferes with subsequent symbols. This is an unwanted phenomenon as the previous symbols have similar effect as noise, thus making the communication less reliable. The spreading of the pulse beyond its allotted time interval causes it to interfere with neighboring pulses.ISI is usually caused by multipath propagation or the inherent linear or non-linear frequency response of a communication channel causing successive symbols to blur together.

1) How to encounter ISI

For multicarrier data transmission model, instead of a single carrier frequency, multiple frequencies are used which are known as sub carriers or sub-frequencies. Dividing our signal bandwidth B into N linearly modulated sub-systems in parallel, each with sub-channel bandwidth $B_N = \frac{B}{N}$, then $B \ll B_c$ ensures relatively flat fading on each sub-channel i.e. each subchannel experiences little to no ISI degradation.

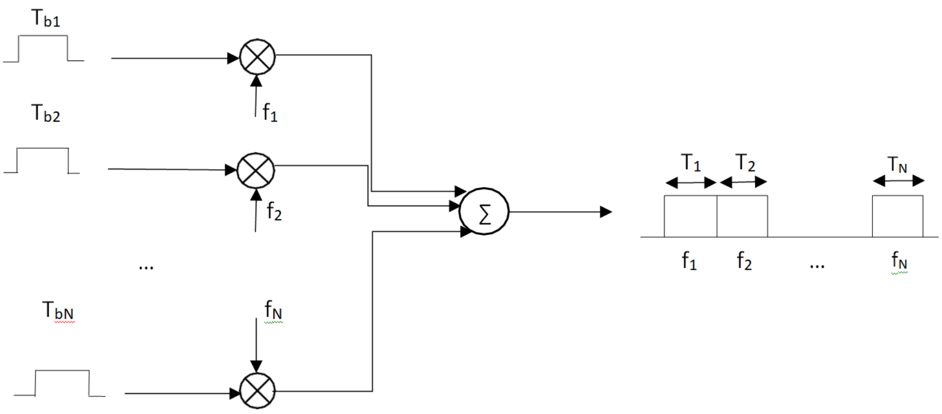

Figure 3

Symbol duration ,$T_s = NT_b$ (T_b is bit duration), should be much larger than the delay spread i.e. $T_s \gg T_m$ order to exhibit flat fading to such signal. However, each of these sub-frequencies occupy the entire symbol duration and tend to interfere with each other. For this reason, in practical situations, these frequencies are chosen in such a way that they are orthogonal to each other. When we use N orthogonal sub-frequencies $f_1 f_2 \dots f_N$ in a symbol duration, we see that the peak/maxima of a particular sub-carrier (f_n) is located at the minima of its adjacent sub- carriers (f_{n-1} and f_{n+1}), which confirms the orthogonal property between the sub-carriers.

Frequency domain representation of these sub-carriers will look like **Figure 5**

So when all these orthogonal sub-carriers $f_1, f_2, \dots f_N$ are included within a symbol duration $T_S = NT$, then the combined spectrum would look like **Figure 6**

Such a signal is called Orthogonal Frequency Division Multiplexing (OFDM) signal. With the help of this OFDM signal it is possible to achieve very fast data rate and eliminate frequency selective fading simultaneously. But it is quite difficult to generate such sub-frequencies $f_1, f_2 \dots f_n$ which maintain orthogonality. To resolve this issue, we use the Inverse Discrete Fourier Transform (IDFT) to generate the OFDM signal. The inverse discrete Fourier transform or IDFT of a signal is represented as:

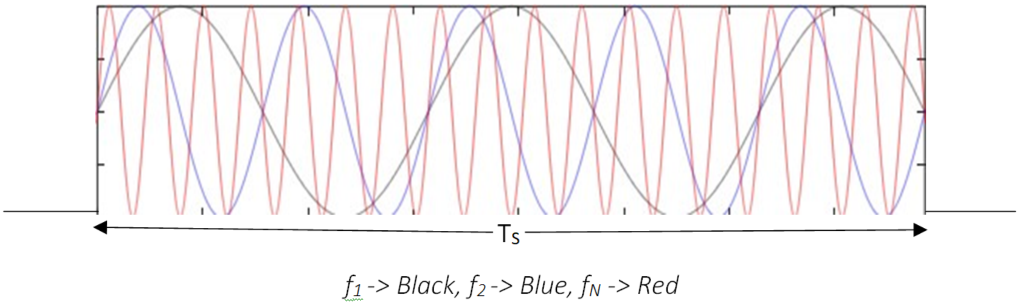

Figure 4

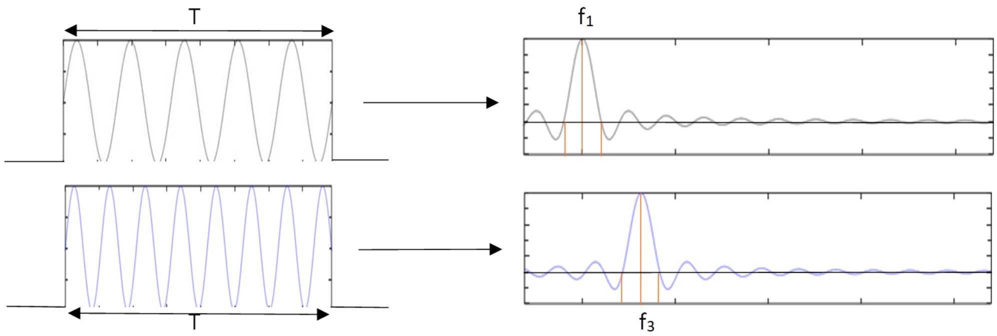

Figure 5

$$x(n) = \sum_{k=1}^{N-1} X(k) \exp j\frac{2\pi}{N} kn$$

where $x(n)$ is the IDFT of the sequence $X(k)$ of length N. Hence, IDFT acts as the building block for OFDM communication.

Generating OFDM signal

Let us assume our OFDM signal consists of symbols with each symbol consisting of N bits. Now we can represent the N data bits inside the k^{th} symbol as: $a_{k,0}, a_{k,1}, a_{k,2} \ldots a_{k,N-1}$ Here the first subscript represents the k^{th} symbol and the second subscript represents the input data bit.

So a_k,n represents information on the nth bit inside the k^{th} symbol interval, where $k = 0, 1, 2 \ldots \infty$ and n=0,1,2...N-1.

Symbol interval is $t \in [kT, kT + T]$, , where T is the symbol interval.

Let the orthogonal sub-carrier frequencies be $\varphi_n(t)$ here n represents the nth sub-carrier frequency, then the complex envelope of the OFDM signal can be represented as:

$$v(t) = \sqrt{\frac{2E_s}{T_s}} \sum_{k=0}^{\infty} \sum_{n=0}^{N-1} a_{k,n} \varphi_n(t - kT)$$

where $\sqrt{\frac{2E_s}{T_s}}$ is the average power of each bit with a duration of T_s.

So, the k^{th} symbol (duration of $T = NT_s$) is formed by:

$\vec{a_k}$ =$a_{k,0}, a_{k,1}, a_{k,2} \ldots a_{k,N}$ where $\vec{a_k}$ represents the data vector associated with the k^{th} symbol.

Since $\varphi_n(t)$ is a set of complex orthogonal waveforms, it can be represented with the help of N complex roots of unity by:

$$\varphi_n(t) = \exp\left[j2\pi\left(f_c + \left(n - \frac{N-1}{2}\right)\right)\frac{t}{T}\right], \text{ when } t \in [0, T]$$
$$\varphi_n(t) = 0, \text{ elsewhere}$$

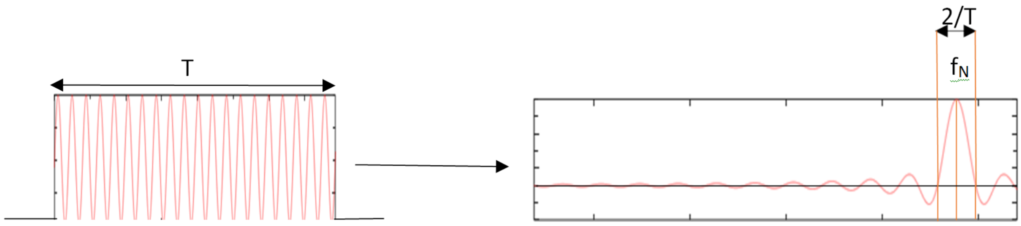

Figure 6

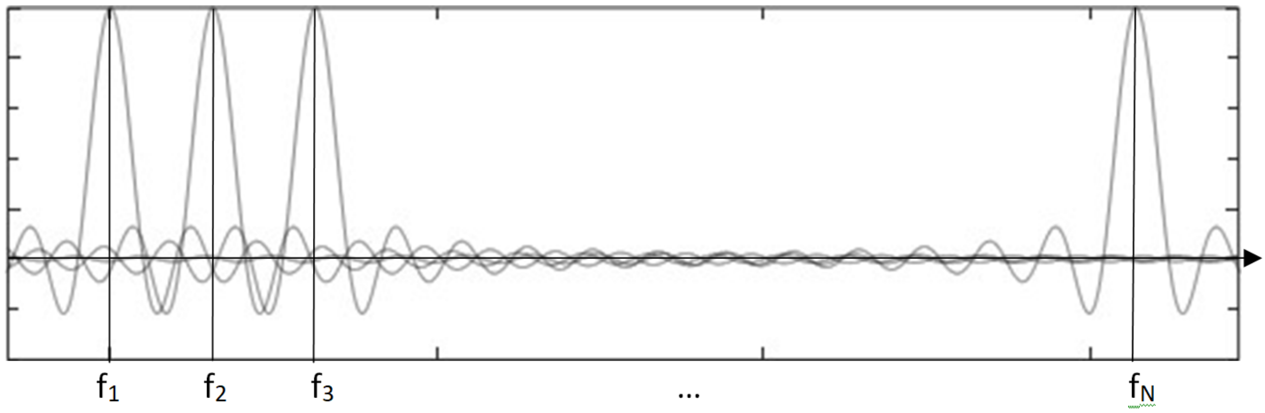

Figure 7

Since we are considering envelope part only, we can omit $\exp[j2\pi(f_c + (n - \frac{N-1}{2}))\frac{t}{T}]$ from the above expression and write:

$$\varphi_n(t) = \exp[j\frac{2\pi nt}{T}] \text{, when } t \in [0, T]$$
$$\varphi_n(t) = 0, \text{ elsewhere}$$

Now considering the first symbol(k=0) envelop, the OFDM signal is

$$v(t) = \sqrt{\frac{2E_s}{T_s}} \sum_{n=0}^{N-1} a_{0,n}\varphi_n(t)$$
$$v(t) = \sqrt{\frac{2E_s}{T_s}} \sum_{n=0}^{N-1} a_{0,n} \exp[j\frac{2\pi nt}{T}], \text{ for } 0 \leqslant t \leqslant NT_s$$

Now, if we sample the envelop $v(t)$ at $t = lT_s, l = 0, 1, 2, ...\infty$ at each bit, we receive the samples as:

$$A_0, l \triangleq v(t) = \sqrt{\frac{2E_s}{T_s}} \sum_{n=0}^{N-1} a_{0,n} \exp[j\frac{2\pi nlT_s}{NT_s}]$$
$$= \sqrt{\frac{2E_s}{T_s}} \sum_{n=0}^{N-1} a_{0,n} \exp[j\frac{2\pi nl}{N}]$$

$a_0 = a_{0,0}, a_{0,1}...a_{0,N-1}$ are the input data sequence and the IDFT of this set of N data values yields the time samples $A_0 = A_{0,0}, A_{0,1}, ...A_{0,N-1}$.
These set of time samples are first passed through a digital to analog converter and receive $v(t)$.

Now, $v(t)$ is used to modulate the carrier in the up-converter which produces our desired OFDM signal:

$$x(t) = Re[v(t)\exp(j2\pi(f_c - \frac{N-1}{2T})t]$$

Thus, our OFDM signal $x(t)$ has been generated and ready for transmission.

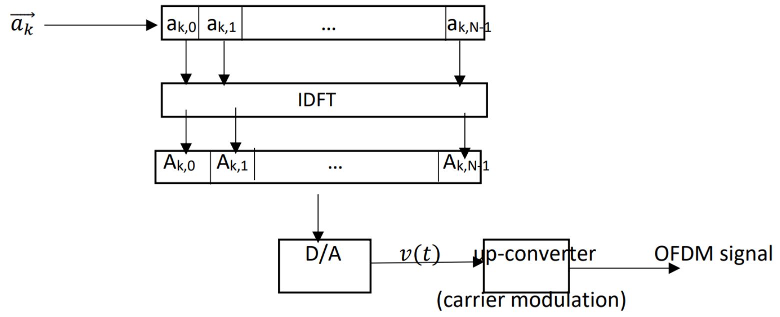

Figure 8

Circular Convolution Problem

These OFDM symbols are successively transmitted through the channel having an impulse response $h(n)$. The signal that is received at the receiver end is the channel output which can be written as the linear convolution between the transmitted signal x_n and the channel impulse response $h(n)$.

Channel output,

$$y(n) = x(n) * h(n) = h(n) * x(n) = \sum h(k)x(n-k)$$

On the other hand x(n) is the IDFT of the N modulated data inputs and since we want to exploit the DFT property, we find the channel output as multiplication of DFT of 2 sequences which is the same as circular convolution of those 2 sequences in time domain.

$$y(n) = x(n) \circledast h(n) = h(n) \circledast x(n) = \sum h(k)x(n-k)_N$$

where, $x(n-k)_N$ denotes $x(n-k)$ modulo N which implies, $x(n-N)_N = x(n)$ i.e. $x(n-k)_N$ is nothing but the periodic version of $x(n)$. According to DFT property, performing circular convolution in time domain is the same as performing multiplication in frequency domain,

$$Y(k) = DFT[y(n)] = DFT[x(n) \circledast h(n)] = X(k)H(k)$$

where, $Y(k), X(k), H(k)$ are the N point DFT of $y(n), x(n), h(n)$ respectively, $0 \leqslant k \leqslant N-1$

$$\therefore Y(k) = X(k)H(k)$$
$$\implies X(k) = \frac{Y(k)}{H(k)}$$
$$\implies x(n) = IDFT[\frac{Y(k)}{H(k)}$$
$$\therefore x(n) = IDFT[\frac{DFT[y(n)]}{DFT[h(n)]}$$

This above algorithm is used in the receiver to extract the required input information sequence $x(n)$ provided that channel impulse response $h(n)$ is known.

Even though we want to calculate channel output in terms of circular convolution so we can use DFT properties for input data recovery, the fact still remains that the channel output is not a circular convolution but a linear convolution between input data sequence and channel impulse response.

In order to make the results of linear convolution same as circular convolution, we can use the well known zero padding method i.e. if the lengths of $x(n), h(n)$ are N, l respectively and $N > l$, then $(N-l)$ zeros are padded with $h(n)$ to make the length of $h(n)$ same as that of $x(n)$.
Instead of padding zeros in the channel impulse response $h(n)$, we use an alternative approach of adding a specific prefix to the input sequence $x(n)$, called the cyclic prefix to solve the issue.

Demonstrating Role of Cyclic Prefix as a Solution

In telecommunications, the term cyclic prefix refers to the prefixing of a symbol, with a repetition of the end. The receiver is typically configured to discard the cyclic prefix samples, but the cyclic prefix serves two purposes:

- It provides a guard interval to eliminate intersymbol interference from the previous symbol.
- It repeats the end of the symbol so the linear convolution of a frequency-selective multipath channel can be modeled as circular convolution, which in turn may transform to the frequency domain via a discrete Fourier transform. This approach accommodates simple frequency domain processing, such as channel estimation and equalization.

The simple frequency domain equalizer is possible only if the channel performs circular convolution. But in nature, all channels perform linear convolution. The linear convolution can be converted into circular convolution by adding Cyclic Prefix (CP) in the OFDM architecture. The addition of CP makes the linear convolution imparted by the channel appear as circular convolution to the DFT process at the receiver.
The key ideas behind adding cyclic prefix :

- Convert linear convolution in to circular convolution which eases the process of detecting the received signal by using a simple single tap equalizer.
- Help combat ISI and ICC.

Principle
A cyclic prefix is often used in conjunction with modulation to retain sinusoids' properties in multipath channels. It is well known that sinusoidal signals are eigenfunctions of linear, and time-invariant systems. Therefore, if the channel is assumed to be linear and time-invariant, then a sinusoid of infinite duration would be an eigenfunction. However, in practice, this cannot be achieved, as real signals are always time-limited. So, to mimic the infinite behavior, prefixing the end of the symbol to the beginning makes the linear convolution of the channel appear as though it were circular convolution, and thus, preserve this property in the part of the symbol after the cyclic prefix.

Let us consider a channel input sequence of length N as: $x(n) = x(0), x(1), ...x(N-1)$, where symbol duration $T = NT_s$, T_s is the data or sampling interval. Finite channel impulse response of the length μ as: $h(n) = h(1), h(2), ...h(\mu)$, where $\mu < N$
The cyclic prefix of the length μ of $x(n)$ is defined as the last μ values of the sequence $x(n)$, $[x(N-\mu), x(N-(\mu-1)), x(N-(\mu-2)), ...x(N-1)]$ Now, for each input sequence of length N, this cycle prefix i.e. the last μ samples of $x(n)$ are appended to the beginning of $x(n)$. Thus, the resulting sequence of length $N+\mu$ is:

$\tilde{x(n)} = x(N-\mu), x(N-(\mu-1), x(N-(\mu-2)...x(N-1), x(0), x(1), x(2)...x(N-\mu-1), x(N-\mu), x(N-\mu+1)...x(N-2), x(N-1)$, where $-\mu \leqslant n \leqslant N-1$
$x(\tilde{-\mu}), ...x(\tilde{-1}) = x(N-\mu), ...x(N-1)$
So, we can write $\tilde{x(n)} = x(n)_N$, for $-\mu \leqslant n \leqslant N-1$
In general, $x(n\tilde{-}k) = x(n-k)_N$ for $-\mu \leqslant n \leqslant N-1$

Suppose, in place of $x(n)$ we use $\tilde{x(n)}$ as the input to our DT channel with impulse response $h(n)$, then the channel output$y(n)$ will be:

$$\begin{aligned} y(n) &= \tilde{x(n)} * h(n) \\ &= \sum_{k=1}^{\mu} h(k)x(\tilde{n-k}) \\ &= \sum_{k=1}^{\mu} h(k)x(n-k)_N \\ &= x(n) \circledast h(n) \end{aligned}$$

Therefore, we can say that the linear convolution between $\tilde{x(n)}$ and $h(n)$ is equivalent as the circular convolution of $x(n)$ and $h(n)$.

At the receiver, only $x(n)$ is required, so the cyclic prefix values from $-\mu$ to -1 are discarded.
This is because $y(n)$, exists for $-\mu \leqslant n \leqslant N-1$ has a length N+μ and the first μ samples $y(-\mu),...y(-1)$ are not needed to reconstruct $x(n)$, as those μ samples or cyclic prefix already exists in $x(n)$ and are redundant.

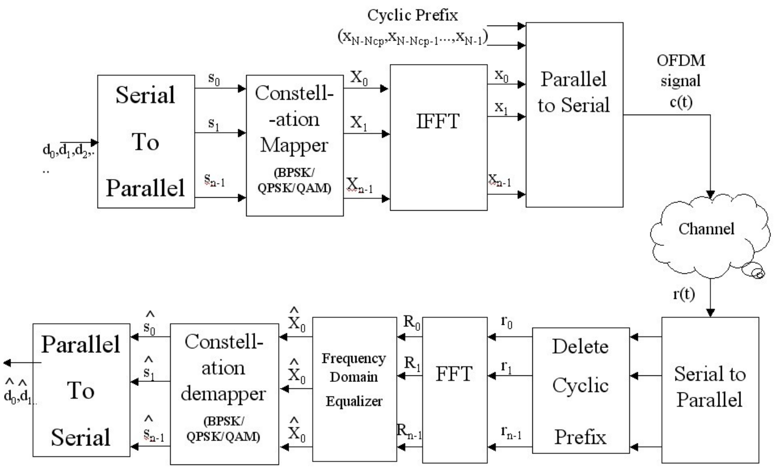

Figure 9: An OFDM communication Architecture with Cyclic Prefix

Mitigation of ISI

Cyclic prefix is helps in eliminating inter-symbol interference (ISI) introduced by the channel.
If we assume our input data block consists of N symbols and a cyclic prefix of length μ is appended to each data block $x(n)$ to form $\tilde{x(n)}$, then we see that only the first μ samples of the channel output $y(n) = h(n) * \tilde{x(n)}$ are corrupted by ISI, which are associated with the last μ samples of the previous data symbol of $x(n)$, due to overlapping resulting from delayed replicas of the same data symbol.

This is because the channel impulse response is of length μ, only the first μ samples of a single data block $\tilde{x(n)}$ of $N+\mu$, are affected by ISI and the successive N samples remain unaffected(Assuming delay spread of channel $T_m < \mu T_s$).

So, when the cyclic prefix part of length μ is removed from the data blocks at th receiver, the overlapped corrupted portion gets removed automatically, and due to the redundancy of cyclic prefix, no additional information is lost from the sequence.
Hence, we are able to extract our desired message signal with no corruption.
There are certain demerits of adding a cyclic prefix:

- Since μ symbols are added to each input data block, there is an overhead of $\frac{\mu}{N}$ and it results in a data reduction of $(\frac{N}{\mu+N})$.

- The transmitted power associated with sending the cyclic prefix is wasted because the prefix is redundant and is discarded at the receiver end.

The benefits of using cyclic prefix are far more superior compared to its few disadvantages, and thus it can be labelled as an effective method of eliminating ISI as well as mitigating the circular convolution problem in OFDM.

OFDM Transmitter

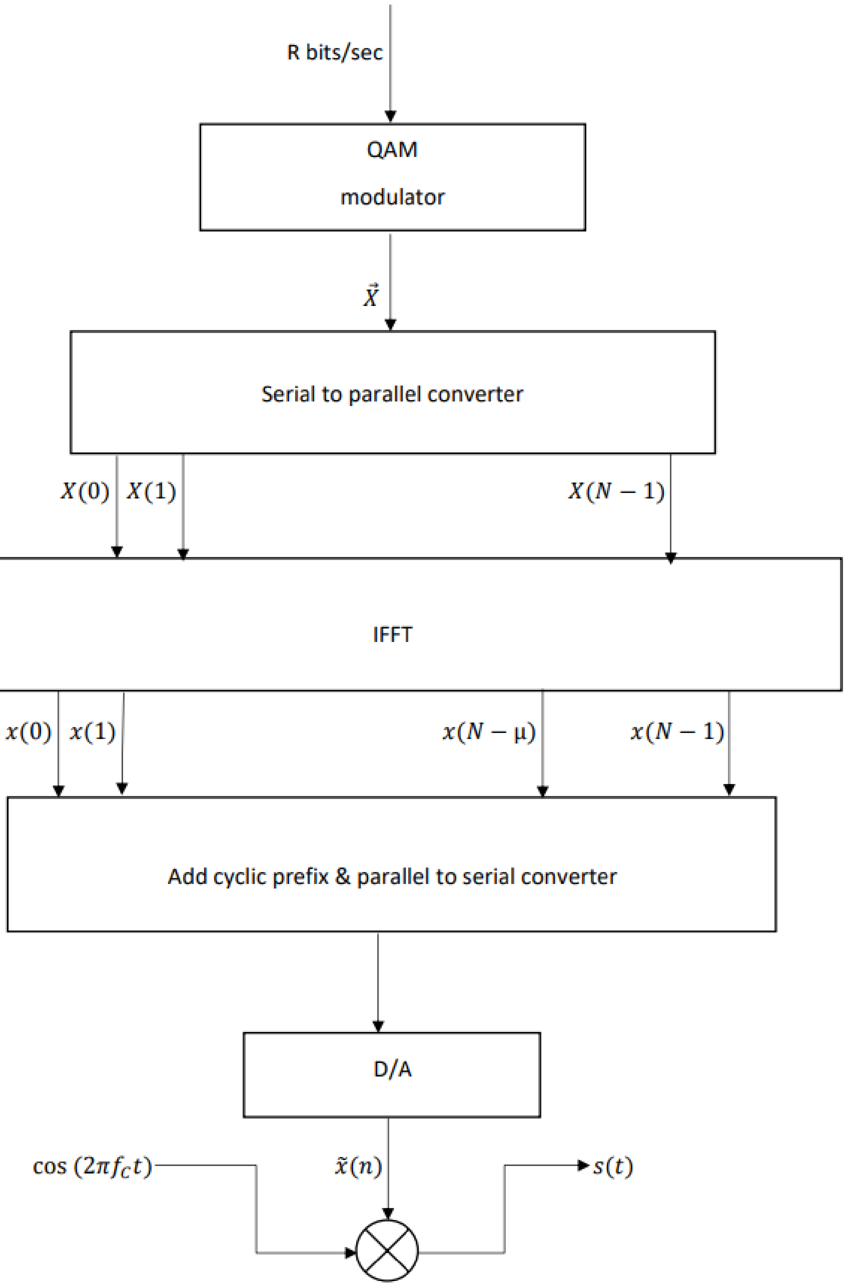

Figure 10

OFDM Receiver

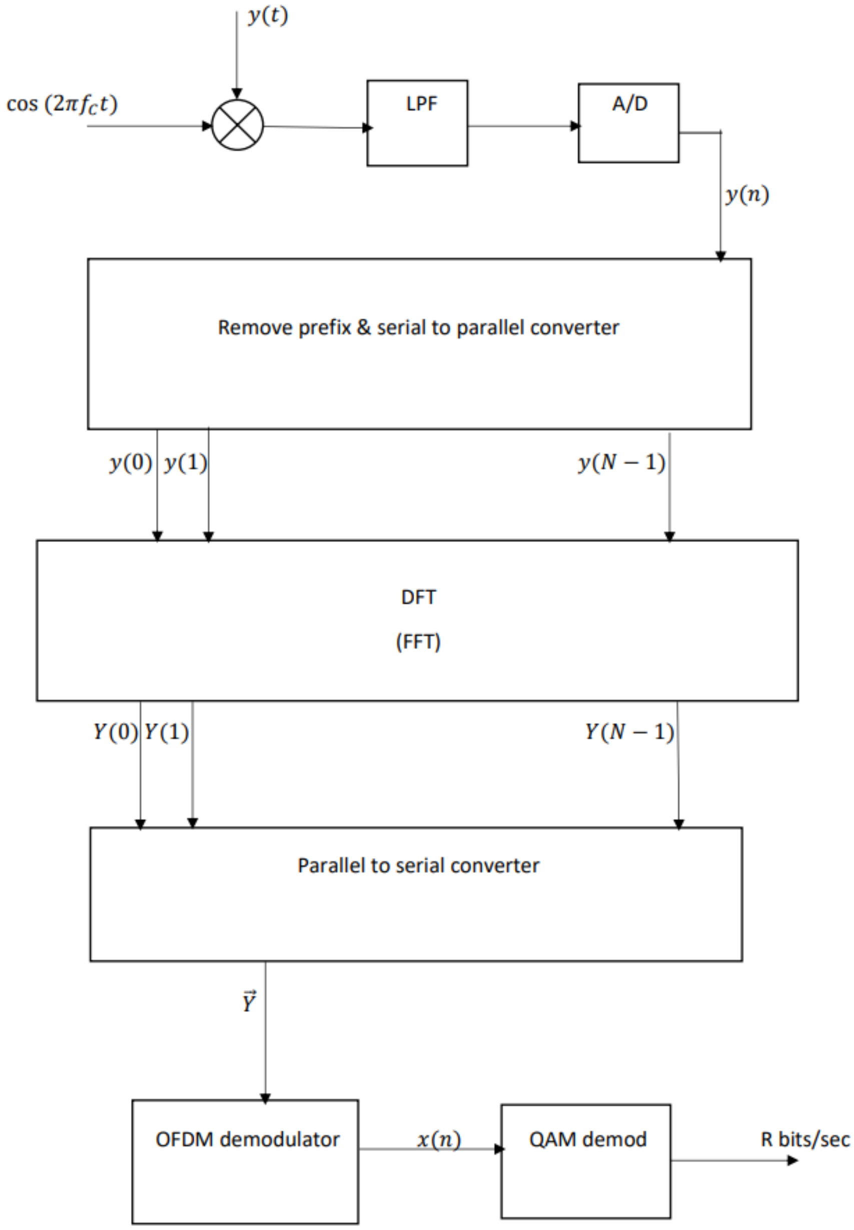

Figure 11

Conclusion

OFDM technology was used to solve the problem of Frequency Selective Fading. Inter-symbol Interference was also eluded through OFDM signal. The problem of circular convolution, i.e, the signal output being in linear convolution, is not possible as the signal is always time limited. So, to mimic the infinite behavior, prefixing the end of the symbol to the beginning was done through cyclic prefix so to make the linear convolution of the channel appear as though it were circular convolution, and thus, preserve this property in the part of the symbol. Thus, this helped in the mitigation of ISI in the signal channel. OFDM has numerous applications and such of those are presented in the report.

Bibliography

[1] S. Dixit and H. Katiyar, "Performance analysis of OFDM under frequency selective fading in varying power delay profile," 2016 International Conference on Emerging Trends in Electrical Electronics Sustainable Energy Systems (ICETEESES), 2016, pp. 213-215, doi: 10.1109/ICETEESES.2016.7581387.

[2] Saurabh Dixit, Himanshu Katiyar, Arun Kumar Singh, "MIMO-OFDM in a Cooperative Frequency Selective Fading Channel: An Analysis", Journal of Computer Networks and Communications, vol. 2019, Article ID 9107505, 7 pages, 2019. https://doi.org/10.1155/2019/9107505

[3] S. Viswasom and D. Murali, "Effect of cyclic prefix reduction on OFDM-CDMA systems," 2013 Annual International Conference on Emerging Research Areas and 2013 International Conference on Microelectronics, Communications and Renewable Energy, 2013, pp. 1-4, doi: 10.1109/AICERA-ICMiCR.2013.6575961.

[4] Steendam, Heidi Moeneclaey, Marc. (1998). Optimization of OFDM on frequency-selective time-selective fading channels. 398 - 403. 10.1109/ISSSE.1998.738105.

[5] Rindhe, Baban Narayankhedkar, Santosh. (2010). Effects of cyclic prefix on OFDM system. 420-424. 10.1145/1741906.1741996.