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ADVANCE WIRELESS NETWORKS (22MCN23T)

Assignment Report

On

Comparative Analysis between SC-FDMA vs. OFDM in Wireless Communication System

Submitted by

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DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

Bengaluru– 560059

CERTIFICATE

Certified that the project work titled **" Comparative Analysis between SC-FDMA vs OFDM in Wireless Communication System "** carried out by **Hitha S (1RV21SCN04)**, **Rakshitha K Manru (1RV21SCN11)**, a bonafide student, submitted in partial fulfillment for the award of **Master of Technology** in **Computer Network and Engineering** of **RV College of Engineering®, Bengaluru, affiliated to Visvesvaraya Technological University, Belagavi,** during the year **2021-22**. It is certified that all corrections/suggestions indicated for internal assessment have been incorporated in the report. The assignment report has been approved as it satisfies the academic requirement in respect of said course prescribed for the said degree.

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1. Introduction

Wireless networks for uplink transmissions from mobile units to base stations include LTE and 5G New Radio (NR). In B5G (Beyond 5G), SC-FDMA may be used for sub-THz communications. SC-FDMA is also known as Single-Carrier OFDM (SC-OFDM), Discrete Fourier Transform spread OFDM (DFT-s-OFDM), and Linearly Precoded OFDM Access (LP-OFDMA). SC-FDMA is based on the idea of OFDM, but precodes the input signal so that the output OFDM mimics the properties of a single-carrier modulated signal within the same transmission bandwidth. Because OFDM is the primary transmission modulation scheme used by SC-FDMA, the communications system maintains the benefits of OFDM, including time-frequency user multiplexing, resistance to frequency-selective fading, and frequency-domain equalization, which is typically simpler to implement than time-domain filter-based equalization. The main benefit of SC-FDMA is that its transmit signal has a lower peak-to-average power ratio (PAPR) than that of OFDM. Numerous sinusoids with different frequencies and phases can be found in one OFDM symbol. A very high peak amplitude in relation to the average power of the signal is produced by the constructive interference between sinusoids that can occur when the many sinusoids are superimposed. High PAPR is a problem in both the digital and analogue worlds. When a digital signal is converted to an analogue signal in the digital domain, a high PAPR denotes that the output signal occasionally exceeds the dynamic range of the DAC. Another benefit of SC-FDMA is its resistance to spectral nulls caused by frequency-selective fading. A null in a subcarrier causes data loss in that subcarrier in OFDM. Since the input signal in SC-FDMA spreads across subcarriers, a null in a subcarrier will also spread across the subcarriers (hence the name DFT-s-OFDM, which refers to the spreading effect).

SC-FDMA (Single-Carrier Frequency Division Multiple Access):

A modulation and multiple access scheme known as SC-FDMA, or Single-Carrier Frequency Division Multiple Access, is frequently used in 4G LTE (Long-Term Evolution) networks. The uplink (UL) transmission of data from user devices to cell towers or base stations makes extensive use of it. SC-FDMA's salient attributes include:

- Power Efficiency: SC-FDMA is known for its power-efficient characteristics, making it suitable for mobile devices with limited battery capacity. It reduces the Peak-to-Average Power Ratio (PAPR), helping conserve energy in user equipment.

- Reduced Interference: SC-FDMA is designed to minimize interference, making it suitable for multi-user environments where multiple devices are transmitting simultaneously.

- Orthogonality: Like OFDM, SC-FDMA maintains orthogonality between its subcarriers, ensuring efficient spectral utilization.

OFDM (Orthogonal Frequency Division Multiplexing):

OFDM, or Orthogonal Frequency Division Multiplexing, is a modulation and multiple access scheme used in a wide range of wireless communication systems, including 4G LTE and 5G networks. OFDM is known for its versatility and efficiency and is used in both downlink (DL) and uplink (UL) transmissions. Key features of OFDM include:

- Wide Applicability: OFDM is widely used in various wireless technologies, including Wi-Fi, digital television broadcasting, 4G LTE, 5G, and more. Its adaptability makes it a core modulation scheme in modern wireless communication.

- High Spectral Efficiency: OFDM efficiently utilizes available spectrum by dividing it into multiple orthogonal subcarriers. This allows for high data rates and improved resistance to multipath interference.

- Flexibility: OFDM can adapt to different channel conditions by adjusting the modulation and coding schemes on individual subcarriers, ensuring robust communication in varying environments.

In summary, SC-FDMA is a modulation and access scheme with a primary focus on power efficiency and interference reduction, primarily used in the uplink of 4G LTE networks. In contrast, OFDM is a versatile and widely applied scheme used in various wireless technologies, including 4G LTE, 5G, and beyond, for both uplink and downlink transmissions, offering high spectral efficiency and adaptability. Understanding the differences between these two schemes is essential for comprehending the nuances of modern wireless communication systems.

2. Literature survey

[1] Simulation And Analysis Of SC-FDMA Based Cellular Systems For LTE Uplink Transmission.

Source: G. B. S. R. Naidu · V. Malleswara Rao, © Springer Science Business Media, LLC 2017

Paper Details: SC-FDMA is the major enabling technique for today's wireless communication. It is mainly adopted in the uplink of LTE and LTE-A cellular systems. OFDMA is another key technique employed in downlink of current wireless systems. These techniques offers benefits like increase in throughput, bandwidth efficiency, data rate and less interference.

Apart from these advantages it suffers from the problem of high PAPR over a journey 4G to 5G. Although, there is extensive work done in this aspect, still there is a gap to further reduce the PAPR and improve the efficiency of next generation wireless networks. In this paper, the performance evaluation of SC-FDMA and OFDMA is carried out in LTE physical layer using various probabilistic schemes (PTS and SLM), adaptive modulation shift keying (Mary-PSK and Mary-QAM) by considering the parameters like PAPR. The study of various research papers tells that the PTS has a better PAPR reduction than SLM and when companding is, performed μ-lawyields good results compared to A-law. However, the proposed companded-PTS obtains low PAPR than conventional methods like μ-law companding PTS and SLM.

Key techinques: Selective Mapping Technique, Partial Transmit Sequence

Challenges: SC-FDMA has low PAPR when compared with OFDMA

[2] BER, SNR and PAPR Analysis of OFDMA and SC-FDMA

Source: Karthik Kumar Vaigandla1*, Dr.N.Venu Balaji Institute of Technology and Science, Warangal, Telangana, India, ISSN NO : 1869-9391

Paper Details: Communication between the transmitter and receiver is made possible by wireless communication, which is seen as the future trend. In order to send the signal through the channel, the signal has been modified after it is generated in each of the multiple sub carriers. Modulation schemes Orthogonal Frequency Division Multiple Access (OFDMA), Single Carrier Frequency Division Multiple Access (SC-

FDMA) and others are compared. OFDM was used earlier, but it had a lot of disadvantages, such as Doppler shift issues and frequency synchronization problems, Power efficiency is low and peak to average ratio (PAPR) is high. In Long-Term Evolution (LTE), the downlink and uplink technologies are OFDMA and SC-FDMA, respectively. OFDMA and SC-FDMA transceiver are described in this paper along with their differences.

Key techniques: An OFDMA and SC-FDMA system with AWGN channel was evaluated for its SER and PAPR performance. As a result of its robustness against interference from multiple carriers, LFDMA has better SER performance than IFDMA and DFDMA techniques

Challenges: FDMA and DFDMA almost have the same PAPR performance. LFDMA and DFDMA are less efficient than IFDMA in OFDMA

[3] BER Evaluation In LTE SC-FDMA Under Multipath Channels

Source: Sahar Ebadinezhad, Saddam Hasan, International Journal of Recent Technology and Engineering (IJRTE) , ISSN: 2277-3878, Volume-8, Issue-4, November 2019

Paper Details: Channel equalization is very essential step in Single Carrier Frequency Division Multiple Access (SC-FDMA) transmission for overcoming the inter-symbol interference (ISI). Also, to evaluate the data-link and network scheduling of LTE technique, a particular channel modelling is crucial. Due to the techniques' complexity and requirement of high bandwidth for data transmission in literature, we motivated to perform a comparative analysis for BER reduction in SCFDMA scheme with and without equalizer. Therefor, in order to enhance efficiency of performance and functionality of network application, due to huge demand for lower delay, latency and higher speed by the modern users, BER reduction is a significant factor for enhancing signal quality. The substantial focus of this research is to improve the uplink signal of LTE technology by using two type of linear equalization methods such as zero forcing (ZF) and minimum mean square error (MMSE) at receiver part. Moreover, analysis of BER and SNR for SCFDMA systems are obtained under several channel models and two different sub-mapping. This evaluation is performed for SCFDMA in uplink by aid of adaptive modulation techniques like QPSK. Finally, for evaluating the channel equalization efficiency with SC-FDMA and for investigating the response of an uplink transmitter, MATLAB framework, is applied in this study. The results reveal that PAPR reduction does not have significant impact on BER performance.

Key techniques: The key techniques involved are :

1) Implementing linear equalizers (MMSE, ZFE) on SCFDMA on MATLAB.

2) Applying linear equalizers on both subcarrier mapping methods (IFDMA, LFDMA) for evaluating BER and SNR performance.

3) Applying above mentioned implementations individually on all four channel models (AWGN, Rayleigh, Pedestrian A and Vehicular A channels).

4) BER updating automatically as the simulation progresses for comparing between equalization methods.

Challenges: Improving BER performance maintained in the SC-FDMA scenario by executing an authentic channel equalization and estimation approaches.

[4] Performance Evaluation of LTE Physical Layer

Source: Emna Hajlaoui, National Engineering School of Gabes, Gabes, Tunisia
Jihed Ghodhbane, National Engineering School of Tunis, Tunis, Tunisia
Abdelhakim Khlifi, National Engineering School of Gabes, Gabes, Tunisia
Mouna Ben Hamed, National Engineering School of Gabes, Gabes, Tunisia
Aida Zaier National Engineering School of Tunis, Tunis, Tunisia
Lassâad Sbita, National Engineering School

Paper Details: Wireless networks have undergone an unprecedented expansion in recent years. This can be attributed to the deployment of successive telecommunications generations dedicated mainly to telephony (2nd Generation GSM), multimedia (3rd Generation UMTS) as well as the 4G (Long Term Evolution: LTE). This last brings a real turning point in the profusion and disparity of solutions. In fact, the 3rd Generation Partnership Project Long Term Evolution (3GPP LTE) was outcome by cooperation between groups of telecommunications consortium known as 3rd Generation Partnership Project to improve the Universal Mobile Telecommunications System (UMTS) standard. It supports up to 300 Mbps for downlink data transmission using the Orthogonal Frequency Division Multiplexing (OFDM) modulation and up to 75 Mbps throughput for the uplink using the Single Carrier-Frequency Division Multiple Access (SCFDMA) modulation scheme. The present work aims to study LTE physical layer performance evaluation for downlink transmission. A comprehensive investigation of the LTE performance analysis is presented including the Bit Error Rate (BER) and Block Error Rate (BLER) performance results for different values of the Channel Quality Indicator (CQI) which indicates the highest possible modulation scheme and coding rate, for which the block error rate in the channel decreasesin the LTE physical layer.

Key techniques: Analysing the performance indexes :

- Binary Error Rate (BER).
- Block Error Rate (BLER).
- Signal-to-Noise Ratio (SNR)

Challeneges: Testing and deploying the model with 5G networks

3. Future of the technology

The development of wireless technologies, network rollouts, and the continued demand for effective uplink communication are likely to have an impact on the future of SC-FDMA (Single-Carrier Frequency Division Multiple Access) over the course of the next 4 to 7 years. Although SC-FDMA has typically been associated with 4G LTE networks, its function may change in the following situations during this time:

4G LTE Legacy Networks: SC-FDMA may continue to be used in 4G LTE networks as they coexist with 5G networks. While the focus shifts to 5G, 4G LTE networks will still be operational, and SC-FDMA may be maintained for efficient uplink communication, especially in areas where 5G deployment is not yet widespread.

IoT and mMTC: The Internet of Things (IoT) and massive Machine-Type Communication (mMTC) are expected to become more prevalent. SC-FDMA's power efficiency could find application in certain IoT devices and mMTC scenarios where low power consumption is crucial.

Standardization: The standardization bodies such as 3GPP (3rd Generation Partnership Project) may continue to support SC-FDMA, depending on industry needs and advancements. Any updates or revisions to the standard could influence its usage.

Emerging Markets: In emerging markets where 4G LTE deployments are still expanding, SC-FDMA may continue to be used as a cost-effective solution for efficient uplink transmission.

4. Current scenario in Indian and global context

In the telecommunications industry, SC-FDMA (Single-Carrier Frequency Division Multiple Access) and OFDM (Orthogonal Frequency Division Multiplexing) were applicable in various situations, particularly in 4G LTE and 5G networks. These modulation schemes' precise application and continued usefulness, however, are subject to change. An overview of the general situation in the Indian and global contexts is provided below:

Global Context:

- SC-FDMA in 4G LTE: Around the world, 4G LTE networks primarily use SC-FDMA for uplink (UL) transmission. Because of its lower Peak-to-Average Power Ratio (PAPR) and high power effectiveness, it is well suited for mobile devices with small batteries.
- In both 4G LTE and 5G networks around the world, OFDM is a widely used modulation scheme for both uplink (UL) and downlink (DL) transmissions. Due to its adaptability, sturdiness, and capacity for handling various use cases, OFDM is now the industry standard for wireless communication systems.
- 5G NR and OFDM: The physical layer of 5G networks, including 5G NR (New Radio), is primarily based on OFDM. Massive machine-type communications (mMTC), enhanced mobile broadband (eMBB), and ultra-reliable low-latency communications (URLLC) are just a few of the diverse requirements for 5G that fit well with OFDM's capabilities.

Indian Context:

- As of my most recent update, SC-FDMA was still being used in India's 4G LTE networks for uplink transmissions. This decision made it possible for uplink communication to be power-efficient, which is essential for mobile devices on the Indian market.
- As of my most recent update, India was only beginning to deploy its 5G network. Like the rest of the world, 5G networks in India primarily rely on OFDM modulation for both DL and UL transmissions.

- Coexistence of 4G and 5G: India, like many other regions, was going through a phase where 4G and 5G networks were coexisting. In 4G networks, SC-FDMA would have remained useful as 5G deployments grew.

5. Companies who are working in the field

1. **Qualcomm**: Qualcomm is a leading semiconductor and telecommunications equipment company that has been at the forefront of wireless technology development. They have contributed to the development of SC-FDMA and other wireless communication technologies used in 4G LTE.

2. **Nokia**: Nokia, a global telecommunications and networking solutions provider, has played a significant role in the development and deployment of SC-FDMA in 4G LTE networks.

3. **Ericsson**: Ericsson is another major player in the telecommunications industry that has been involved in the development and implementation of SC-FDMA technology for wireless networks.

4. **Huawei**: Huawei, a Chinese multinational technology company, has been active in the development of wireless communication technologies, including SC-FDMA, for its network infrastructure equipment.

5. **Samsung**: Samsung, known for its diverse technology products, including mobile devices and telecommunications equipment, has contributed to the advancement of SC-FDMA in the context of 4G LTE.

6. **ZTE**: ZTE Corporation, a Chinese multinational telecommunications equipment and systems company, has also worked on SC-FDMA and related technologies for wireless networks.

7. **Intel**: Intel, a major semiconductor manufacturer, has been involved in various aspects of wireless communication technology, and they have contributed to advancements in SC-FDMA technology.

8. **Analog Devices**: Analog Devices is a semiconductor company that has expertise in signal processing and has been involved in the development of technologies related to SC-FDMA.

9. **Broadcom**: Broadcom, a semiconductor and software company, has played a role in the development of wireless communication technologies, including SC-FDMA.

10. **Keysight Technologies**: Keysight Technologies specializes in electronic measurement solutions and has been involved in testing and validation of SC-FDMA and other wireless technologies.

6. MATLAB code

Selection of Modulation type

```
s = rng(11);            % Set RNG state for repeatability

% Simulation parameters
numSym = 6000;          % Number of OFDM symbols to modulate
osf = 8;                % Oversampling factor

% OFDM parameters
N = 256;                % FFT length
cpLen = 16;             % Cyclic prefix length
modOrder = QPSK ;             % QAM modulation order
```

Vary `modOrder` to show how the modulation order impacts PAPR and the bit error rate (BER).

SC-FDMA Design and Transmit Mapping

```
% SC-FDMA parameters
M = 48;                 % Number of subcarriers
L = 1;                  % Subcarrier mapping interval (L=1 for localized)

% Create a random stream of bits, encode them in the desired baseband
% modulation, and map onto an OFDM grid
bitsPerSubcarrier = log2(modOrder);
dataIn = randi([0 1],bitsPerSubcarrier*M, numSym);      % Create a random data stream
ofdmDataGrid = qammod(dataIn,modOrder, ...              % Map the bits into the complex domain
        InputType='bit', ...
        UnitAveragePower=true);
ofdmDataGrid = cat(1,ofdmDataGrid,zeros(N-M,numSym));   % Zero-pad the unused subcarriers

% Take the same data used for OFDM, perform the DFT to precode the
% data, and form an SC-FDMA grid
scfdmaData = fft(ofdmDataGrid(1:M,:),M);                % Precode the data in the M subcarriers

% Map the precoded data via localized (L=1) or distributed (other L) mapping
scfdmaDataGrid = zeros(N,numSym);
scfdmaDataGrid(1:L:M*L,:) = scfdmaData;
```

SC-FDMA Transmitter

```
% Modulate with OFDM
xOFDM   = ofdmmod(ofdmDataGrid,N,cpLen,OversamplingFactor=osf);
xSCFDMA = ofdmmod(scfdmaDataGrid,N,cpLen,OversamplingFactor=osf);
```

PAPR Measurements

```
% Normalize the signal powers so that the average power is the same for
% both signals when comparing PAPR
pwrOFDM = sum(abs(xOFDM))/length(xOFDM);
pwrSCFDMA = sum(abs(xSCFDMA))/length(xSCFDMA);

% Compute and plot the CCDF
pm = powermeter(ComputeCCDF=true,Measurement="Peak-to-average power ratio");
paprs = pm([xOFDM/pwrOFDM xSCFDMA/pwrSCFDMA]);

plotCCDF(pm);
legend('OFDM','SC-FDMA');
```

```
disp(['The PAPR for OFDM is ' num2str(paprs(1)) ' dB']);
```

The PAPR for OFDM is 11.1869 dB

```
disp(['The PAPR for SC-FDMA is ' num2str(paprs(2)) ' dB']);
```

The PAPR for SC-FDMA is 8.0823 dB

```
disp(['The improvement in PAPR from OFDM to SC-FDMA is ' num2str(paprs(1)-paprs(2)) ' dB']);
```

The improvement in PAPR from OFDM to SC-FDMA is 3.1045 dB

SC-FDMA Receiver

```
% Demodulate using OFDM
yOFDM   = ofdmdemod(xOFDM,N,cpLen,OversamplingFactor=osf);
ySCFDMA = ofdmdemod(xSCFDMA,N,cpLen,OversamplingFactor=osf);

% Simulate a notch in the spectrum by nulling the 5th subcarrier
yOFDM(5,:)       = 0;
ySCFDMA(5*L+1,:) = 0;
figure;
plot(abs(yOFDM));
xlim([0 M]);
title('Spectral Notch');
xlabel('Subcarrier');
ylabel('Magnitude');
```

Constellation Graph

While the OFDM constellation is clean, the notched subcarrier creates a subcarrier with no energy, which appears as a constellation point at (0,0).

```
% Despread the SC-FDMA subcarriers
sSCFDMA = ifft(ySCFDMA(1:L:M*L,:),M);
```

Show the effect of a frequency null on the received constellation of the SC-FDMA signal. Try varying the modulation index and observe the BER as the number of bits per symbol increases.

```
figure;
plot(sSCFDMA(:),'x');
title('SC-FDMA Constellation After Spectral Notch');
```

Decode the Two Signals and Compute the Bit Error Rates.

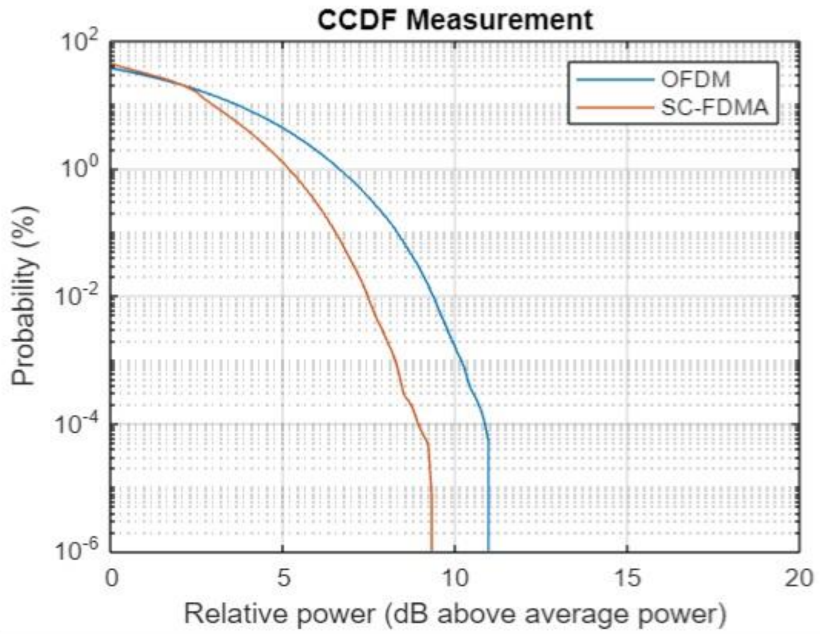
```
% Hard decision decoding
decOFDM   = qamdemod(yOFDM(1:M,:), modOrder, OutputType='bit',UnitAveragePower=true);
decSCFDMA = qamdemod(sSCFDMA, modOrder, OutputType='bit',UnitAveragePower=true);

% BER of notched signal
BER = comm.ErrorRate(ResetInputPort=true);
berOFDM   = BER(dataIn(:),decOFDM(:),true);
berSCFDMA = BER(dataIn(:),decSCFDMA(:),true);

disp(['BER for OFDM with spectral null = ' num2str(berOFDM(1))]);
```

```
BER for OFDM with spectral null = 0.010425
```

```
disp(['BER for SC-FDMA with spectral null = ' num2str(berSCFDMA(1))]);
```

```
BER for SC-FDMA with spectral null = 0
```

7. Results




```
The PAPR for OFDM is 11.0411 dB
The PAPR for SC-FDMA is 9.3078 dB
The improvement in PAPR from OFDM to SC-FDMA is 1.7333 dB
```

Fig 1. CCDF Measurement

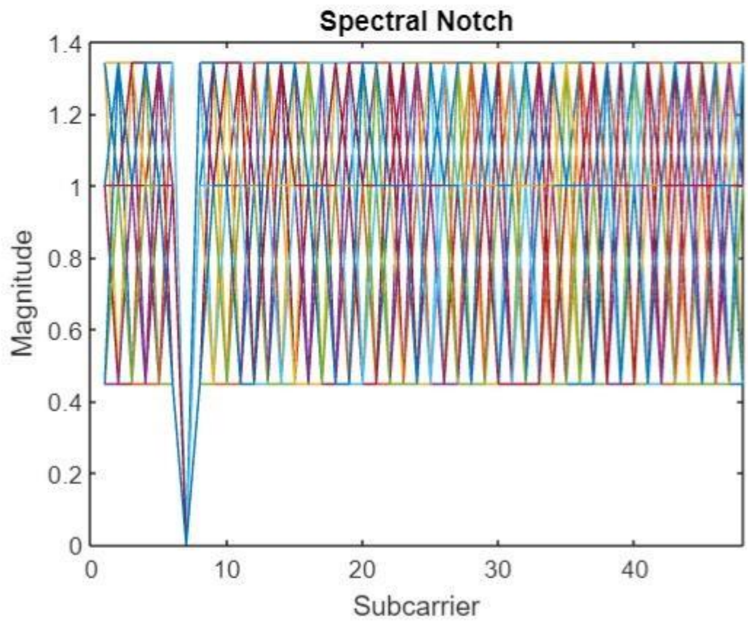


Fig 2: Spectral Notch

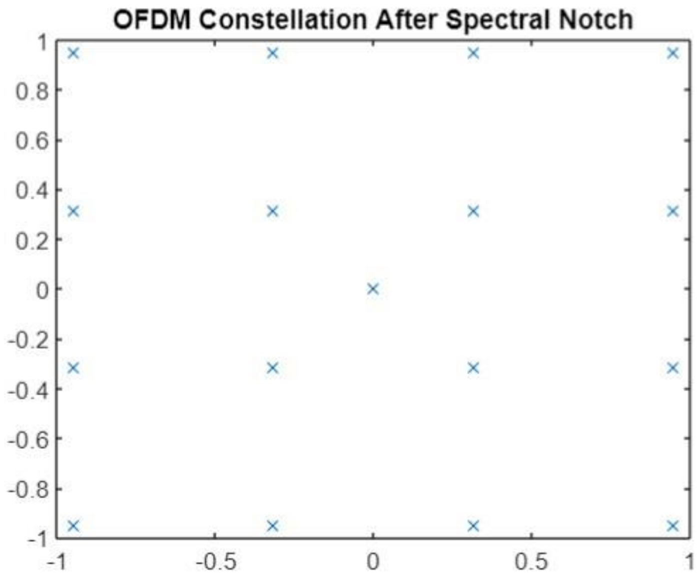
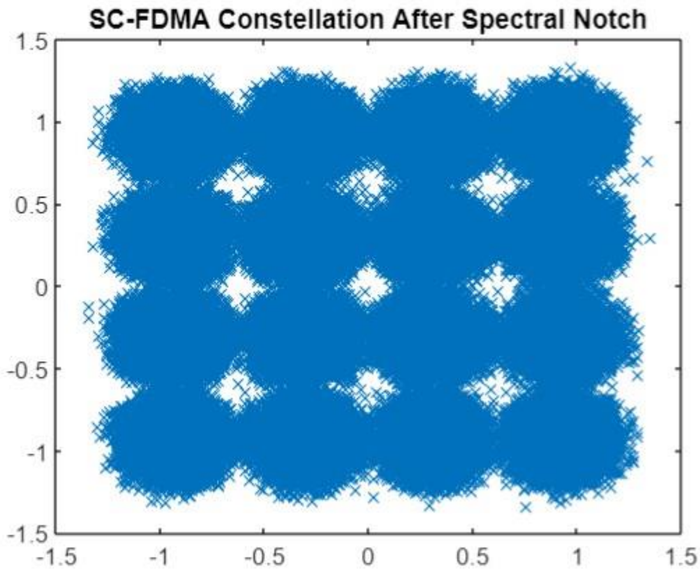


Fig 3: OFDM Constellation after Spectral Notch




```
BER for OFDM with spectral null = 0.01043
BER for SC-FDMA with spectral null = 0.00070312
```

Fig : SC-FDMA Constellation after Spectral Notch

8. References

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