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A SIMULATION STUDY OF USING COMMUNICATION SIGNALS FOR RANGING

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ABSTRACT

Md Abdul Khalek: A simulation study of using communication signals for ranging
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Orthogonal frequency division multiplexing (OFDM) is a massive multicarrier technology which has been widely applied for the huge amount of data transmission in wireless communication. This technology is also more popular due to its advantageous benefits over other modulation schemes such as adaptability in severe channel condition, ability to cope up with new technology, robustness against multi-path effects and the overall transmission quality etc. But there will still remain some issues with OFDM system if it is not properly aligned with suitable wireless scenario. Hence the importance of adjustment of OFDM system with proper parameters in wireless communication is really vast and the matter of huge research for present and future technological advancement. As a trend of development in wireless communication, we worked on two aspects of OFDM system one is OFDM signal for communication, and another is OFDM signal for ranging. However, we carried out the performance of the OFDM system for communication and ranging for wireless signals in MATLAB simulation by this thesis work. The first part of this work is based on the OFDM signal for communication. Here we investigated the communication performance of the OFDM system by applying on AWGN, Rayleigh fading and tapped-delay-line A(TDL-A) channel model with the combination of different parameters, for instance, cyclic prefix (CP) lengths, channel lengths, Quadrature Amplitude Modulation (QAM) schemes. Whenever we think about the OFDM system in multipath scenario, one major impediment inter-symbol interference (ISI) automatically appears in the network which leads to the high bit-error-rate (BER) in the transmission. In order to overcome the dilapidated situation, suitable alignment of CP lengths must be ensured based on the multipath scenario. Another important factor is choosing appropriate modulation schemes because it also plays a vital role in case of data transmission. Modulation scheme allows how many bits will be transmitted. However, all of these combinations have been taken in consideration to achieve the better communication performance. The second part of this research work is based on target localization in OFDM system, we studied here on both the direction-of-arrival (DOA) and Time-of-arrival (TOA) estimation method for OFDM communication. For both the DOA and TOA estimation signal subspace-based Multiple Signal Classification (MUSIC) algorithm has been applied. The subspace-based technique usually divides the covariance matrix into two subspaces, signal subspace and noise subspace. Based on this two subspaces MUSIC returns estimation result smoothly by spectrum searching process. In order to enhance estimation accuracy, first we explored out resolvable angles and resolvable delays with respect to different parameters for DOA and TOA respectively, and then, in case of DOA estimation, how the parameters e.g. signal-to-noise ratio (SNR), the number of snapshots, the number of elements, the number of elements spacing etc. hinder and assist the estimation process. Similarly, in TOA estimation, the effect of SNR, the number of snapshots, the number of subcarriers, the subcarrier spacings have been identified. However, by performing this over all research work, we justified and figured out the issues, finally explored out an innovative high resolution estimation method for both the DOA and TOA towards target localization.

Keywords: OFDM, Cyclic prefix (CP), Modulation, AWGN, Rayleigh fading, Tapped-delay-line (TDL), Multiple Signal Classification (MUSIC), Direction-of-arrival (DOA), Time-of-arrival (TOA).

PREFACE

The thesis work was started at the end of 2019 with the concept of OFDM signal for communication and for ranging given by my supervisor Asst. Prof. Bo Tan. I appreciated his dedication and devotion regarding the help during my thesis work. I am also grateful to him for his strong endeavours which helps to solve the difficulties those I faced many times in my thesis work. Moreover, he has spent lot of times in weekly meeting and provided me huge information for properly writing my thesis paper.

I would like to thank my parents who were always with me specially in my hard time. From the beginning of my life, they are supporting me mentally, financially. I also like to thank all of my friends and family who helped me in my life.

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Md Abdul Khalek

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LIST OF SYMBOLS AND ABBREVIATIONS

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
ASK	Amplitude shift keying
AWGN	Additive White Gaussian Noise
BPSK	Binary Phase Shift Keying
BER	Bit-Error-Rate
CP	Cyclic Prefix
CP-OFDM	Cyclic Prefix Orthogonal Frequency Division Multiplexing
CDMA	Code Division Multiple Access
DOA	Direction-of-Arrivals
ESPRIT	Estimation of Signal Parameters Via Rotation Invariance Technique
FSK	Frequency shift keying
FFT	Fast Fourier Transform
FT	Fourier Transform
GPS	Global Positioning System
ISI	Inter Symbol Interference
ICI	Inter Carrier Interference
IFFT	Inverse Fast Fourier Transform
LOS	Line-of-sight
LTE	Long Term Evolution
LBS	Location Based Service
ML	Maximum likelihood
MUSIC	Multiple Signal Classification
MIMO	Multiple Input and Multiple Output
MCDS	Maximum Channel Delay Spread
NLOS	Non-Line-Of-Sight
OFDM	Orthogonal Frequency Division Multiplexing
PAPR	Peak to Average Power Ratio
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature phase shift keying
QOS	Quality-of-Service

RMS	Root-means-square
SNR	Signal-to-noise ratio
TOA	Time-of-Arrivals
TE	Time Delay
TDL	Tapped-Delay-Line
UTW-OFDM	Universal Time-Domain Windowed OFDM
UF-OFDM	Universal Filter OFDM
WCDMA	Wideband Code Division Multiple Access.

1. BACKGROUND AND LITERATURE REVIEWS

1.1 Background

With the development in science and technology, the evaluation of wireless communication is going ahead in faster speed. The anecdotal development of today's wireless technologies is the result of efforts of hundreds of scientist groups. The development of wireless communication is a series of history; however, the concept of electromagnetic wave mathematically was first established by James Clerk Maxwell in 1873. There was seen a sloth growth in development from 1873 to 1960s. The important breakthrough of modern cellular mobile communication concept was introduced by AT and T Bell laboratories in the 1970s which was the starting of new era in wireless communication. However, a rapid revolution was noticed from 1980s to 2002. The first-generation(1G) was the pioneer in mobile phone technology introduced in wireless communication in the 1980s which was based on narrowband analog system, after a decade the 1G migrated to second-generation(2G) narrowband digital communication systems. Immediate after emerging of 2G, the third generation(3G) wideband digital multimedia communication system deployed worldwide [1]. The evaluation of wireless technologies is an ongoing process, upgrading one after one over the time. Today's fourth generation(4G) wireless technologies are considered as an evaluation of 3G technologies as well as market dominating technologies claimed by different interest groups. However, the unique and major features of 4G technologies is the accommodation of heterogeneous radio access systems which is directly connected to the core networks. Thus, 4G technologies open the new horizon in the field of wireless communication for the individual users facilitating wide variety of accessibilities, high data rate even in high mobility, and strong information security [2]. The latest technology is the today's fifth generation(5G) which is the upgraded standard of 4G mobile telecommunication. 5G is a brilliant emerging technology with high data services, capable of providing simultaneous services even in more densely wireless environment, low transmission latency, supports low power consumption devices, low development cost, and capable of handling overall customer quality-of-services (QOS) [3], [4]. However, with the upgradation in technological generation in mobile telecommunication industries the QOS is also being improved with the same trend due the growing demand of services. Especially, 3G technologies are involve in Code Division Multiple

Access (CDMA) and Wideband Code Division Multiple Access (WCDMA). In comparison, 4G and 5G wireless technologies utilize the Orthogonal Frequency Division Multiplexing (OFDM) with Multiple Input and Multiple Output (MIMO) technologies for sake of improvement of QOS. The basic concept of OFDM is a multicarrier modulation technique that allows high amount of digital data transmission by dividing the spectrum into sub band over radio wave [5]. Therefore, the research on performance of OFDM communication is necessarily important. In this thesis, we tested OFDM system performance over various channel models with different parameters e.g. cyclic prefix (CP) length, Quadrature Amplitude Modulation (QAM) techniques and so forth. In second part of thesis, we tested performance of Multiple Signal Classification (MUSIC) algorithm exploiting in case of both Direction-of-arrival (DOA) and Time-of-arrival (TOA) estimation on OFDM system for communication ranging.

Target localization and position tracking have been a great interest over few decades due the wide application of location-based services (LBS) and navigations [6]. With the advancement of wireless network technologies, the importance of location awareness has been a great attention and crucial factor too [7]. However, OFDM is the basic and key technology that is being used perfectly in beyond 3G or 4G wireless communication [8]. In multipath propagation environment, multiple coherent signal travels in different directions and induced at an antenna array. Due to the multipath propagation, there are greater number of paths appear at antenna array than the original number of sources, therefore, separation of DOA is important [9]. The performance of MUSIC highly depends on the estimation technique. But there are several fault-finding parameters such as SNR, the number of sample snapshots, space between the adjacent elements etc. strongly affect the estimation process [10]. Likewise, in case of TOA estimation for wireless networks, multipath signal propagation is one the major factors that has been considered as a cause of error and degradation of estimation precision. MUSIC is applied to solve this problem even in hostile non-line-of-sight (NLOS) environment; thus this algorithm is used for TOA estimation in OFDM system to mitigate the error and achieve high precision [11]. However, the aim of this thesis is mainly to investigate all these aspects of the OFDM system in communication and figure out the better solution.

1.2 Literature review

1.2.1 Applications of OFDM signal in communication

The OFDM has become more adaptive technology in many wireless communication standards, including satellite communication in china and digital audio broadcasting, terrestrial digital video broadcasting in Europe during few decades. Furthermore, OFDM is approved by many IEEE standard working groups such as IEEE 802.16d/e, IEEE 802.11a/g/n. There are vast applications of OFDM system in long range and short-range communication including wireless personal area networks, wireless local area network, and metropolitan area networks and so on. In Long Term Evaluation (LTE) of 3GPP, OFDM has become a major part of research area among the researchers [12]. Additionally, the OFDM system is utilized for LTE mobile network based-station, LTE downlink transmission for radar/sensing purposes [13]. What is more, a wide verity of OFDM systems have been introduced for conventional 4G and 5G wireless communications, for example, the universal time-domain windowed OFDM (UTW-OFDM), conventional cyclic prefix OFDM(CP-OFDM), universal filter OFDM (UF-OFDM). In conventional 4G wireless communication, CP-OFDM used as a digital encoding scheme. Furthermore, it is also being expected, in 5G and beyond, a CP-OFDM signal will continue to be applied for latest network upgradation [14].

1.2.2 MUSIC in communication and radar system

The basic principle of radar system is that transmits electromagnetic waves towards an interest region or target and received and detects these electromagnetic waves, when reflected back from that interest region [15]. On the other hand, in communication system, signal travels mobile user to base station, and user location usually are tracked at the base station by estimating DOA and TOA [16]. MUSIC basically operates in two domains, time domain and frequency domain for target localization. For estimating DOA, it works in time domain and frequency domain for TOA estimation [17].

The potentiality of the sub space-based MUSIC algorithm is wide for the prevailing wireless communication and radar systems. It is being applied in wireless communication in many ways. However, in terms of communication, signal usually travels from mobile users or mobile station to the base station. The DOA estimation method is used for determining the direction of an incoming signal from a mobile user to a base station. This method ensures unbiased evaluation of arriving signals at the base station by considering the noise in each channel is unassociated, thereby making the noise association matrix diagonal. The incident signal may be somewhat associated, making a non-diagonal matrix signals association [16]. Beside this, the sub-space-based MUSIC has been vastly applied in wide variety of radar systems for its superiority in the aspect of parameters estimation. However, many modified versions of this algorithm already emerged due to the circumstantial demand. For instance, for two-dimensional DOA estimation a fast weighted MUSIC algorithm proposed, extended cyclic MUSIC algorithm, which is strong noise resistive, capable of providing enhanced angle resolution in radar communication. In MIMO radar system, for estimating DOA, a transformation version of MUSIC has been applied [18]. Furthermore, to some extent, conventional MUSIC algorithm is computationally expensive because it searches all the arrival angles of incoming signal. For avoiding this drawback search free DOA estimation method such as Root-Music and ESPRIT have been introduced [19]. Root-Music is one of the class as well as modified version of MUSIC algorithm which enhances the extra capability for target localization. Furthermore, it capable of resolving multiple targets with separation angles smaller than the main lobe width of array antenna [20].

1.2.3 MUSIC in time and joint time-angle estimation

In order to determine target's location accurately two basic estimation paramters DOA and TOA are inevitably needs to be incorporated jointly with high perfection. But the major barrier for both the DOA and TOA estimation is NLOS multipath signal propagation which leads to degradation the estimation performance in many ways [21]. Therefore, using OFDM signals is a promising approach for DOA and TOA estimation by mitigating multipath effects and many estimation methods already have been proposed based on OFDM technology [22]. Though all of the methods are not perfectly sucessive to some extent, on the other hand, modern spectral estimation method, for example, MUSIC algorithm which performs comperatively high resolution estimation with better perfection[23].

1.2.4 MUSIC applied on OFDM signal

In mutipath signal propation environment, ISI is the most common phenomenon and cause of severe signal fading. Therefore, in wireless signal propagation, it is very impportant to estimate signal delays and further channel estimation. However, in order to establish an well communication link without interference and ISI, the implication of estimation of time delays and DOA for incommming signal is profound. Under normal circumstance, match filter technique are usually used to estimate time delay which is baesd on the frequency domain model in the sense of Maximum Likelihood(ML). In general, this technique is capable of providing optimal estimation result in case of only one multipath signal. But, when multiple signals are superimposed together, this techinique is failed to provide optimal estimation result. Therefore, MUSIC is being applied on OFDM signal with a holistic approach to overcome this issue as well as for high estimation precision. Basically this algorithm requires the system to provide known data, so that the algorithm can estimate the signal delay based on the provided equialized and synchronized data by OFDM system. Thus, MUSIC algorithm is being deployed on OFDM system for the sake of high precision target localization [24].

In future communication(6G) to integrate the both communication and sensing function on one signal combined installed system eases to deploy and maintain for aplications including connected vehicles, traffic management, autonomus zones and in rural agricultural development. Therefore, it is vitally important to exploit both the sensing(distance and angle estimation) and communication functions. Radio sensing is an essential aspect in case of detecting drone and other flying objects [25].

The rest of this research report is organized as follows. The basic idea of OFDM communication and OFDM waveform are discussed in chapter 2. The performance investigation of the OFDM communication with different parameters combination over different wireless channel models, result analysis, conclusion and future recommendation are explained in chapter 3. In chapter 4, the performance of MUSIC in terms of DOA and TOA estimation, challenges of the estimation process, solutions and future works are discussed.

2. BASICS OF MULTIPATH AND OFDM

2.1 Multipath propagation

In wireless communication, channel is a medium by which signals are independent to travel from transmitter to receiver in many different ways, for instance, reflecting, scattering, diffraction are subject to wide variety of obstacles between the communication links. This phenomenon is known as multipath propagation [26], [27].The consequence of multipath propagation, multiple copies of transmitted signals are received at receiver with attenuation, phase-shifted, and delayed known as distortion [27], [28]. However, the next generation mobile communication will face more demand on high data rates, higher carrier frequencies, high mobilities as well as stable communication link probability. Basically, the performance of communication system profoundly depends on the wireless channel's characteristics. Therefore, it is important to understand the behaviour of wireless channels for the assessment of their performances [29]. One of the major hindrance for the high data transmission in wireless communication is the multipath delays. If the multipath channel delay is longer than the guard interval e.g., CP, inter symbol interference (ISI) arises in the system. In such a situation, OFDM system was introduced to improve the performance degradation caused by multipath fading. However, even in OFDM system it cannot be possible to avoid ISI, therefore CP was introduced to combat ISI. It is also a difficult task to select appropriate length for guard interval in OFDM system, since the multipath delay fully dependent on the wireless environment. Henceforth, multipath delays vary for different paths [30]. Another important measure for ensuring transmission capacity and required transmission quality is selecting a series of modulation, demodulation, channel coding techniques etc. should perfectly cope accordance with the channel characteristics [31]. In this thesis, we expounded three major different types of wireless channel models considering the various wireless environment e.g., Additive White Gaussian Noise (AWGN), Rayleigh fading, Tapped-delay-line (TDL) in next sections.

2.2 Channel model

2.2.1 AWGN channel

AWGN channel is the most fundamental and suitable channel model in wireless communication which only impairments with a constant spectral density and obeys statistical Gaussian distribution in amplitude. This channel model does not responsible for fading phenomena, for instance, frequency selectivity, interference, and dispersion [32].

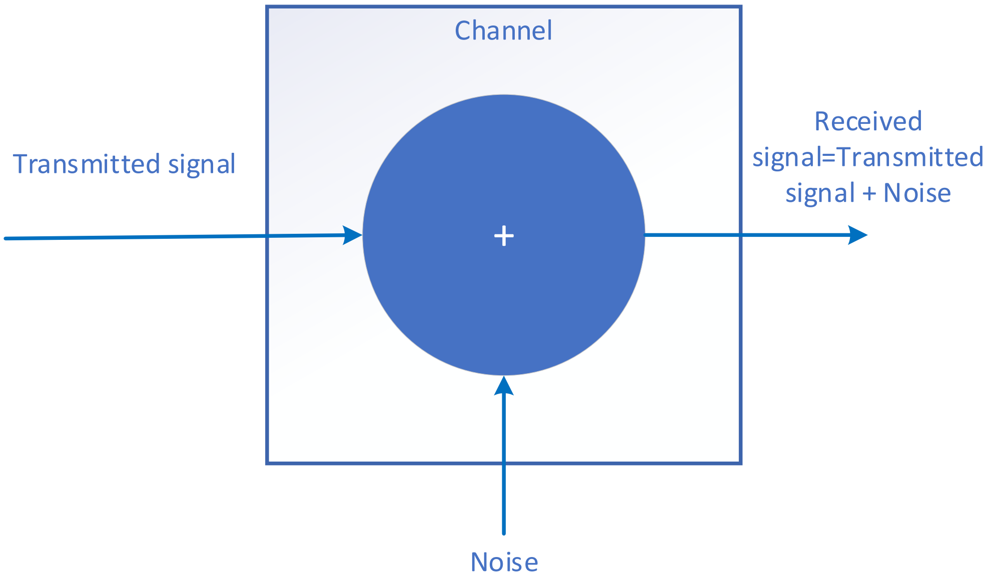


Figure 1. *AWGN channel model*

The channel operates the summation of White Gaussian Noise and in case of real and complex valued input signal shown in Figure 1. If the real valued input signals are fed to the channel, channel will produce summation of real values of noise and output will be real. On the other hand, if the input signal is complex, output signal will be complex too [33].

2.2.2 Multipath channel

In wireless comunication signal usually transmitted through the free space. There are wide varieties of physical mediums ,for example, wireline, microwave radio, and fiber optic cables and so on. No matter, whatever the medium is, the important factor is that the transmitted signal is corrupted randomly by different possible machanisms.

However, the most common form of transmitted signal degradation induces in the form of additive noise that generated at the front end of the reciever often known as thermal noise. Figure 2 depicts the noise inducement process for multipath channel in wireless communication. Additionally, in wireless transmission, other types of noise, for instance, man-made noise and atmospheric noise also picked up at receiving end by the reciever [34].

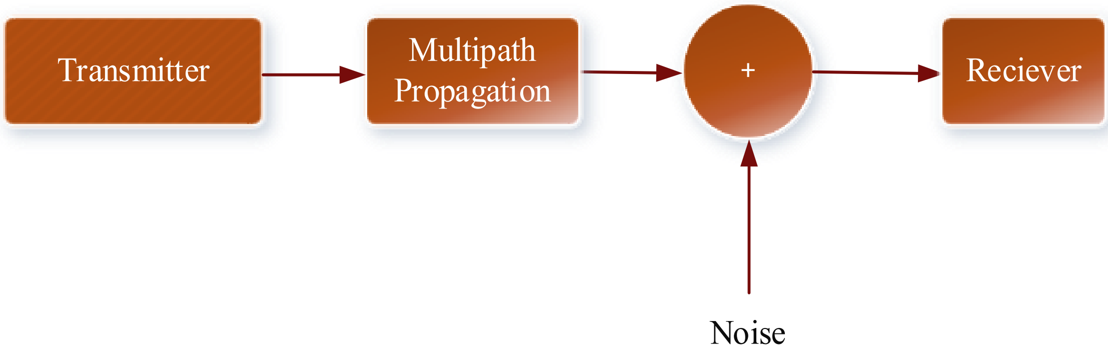


Figure 2. *Noise inducement at receiver in multipath channel*

2.2.2.1 Rayleigh fading

The change of transmitted signal e.g., time, phase, frequency in attenuation with different components is known as fading in multipath communication. Fading is induced due to multipath propagation having obstacles between the transmitter and receiver. The effect of multipath propagation, for instance, time dispersion, doppler shift, scattering are the major features of Rayleigh fading channel shown in Figure 3. In Rayleigh fading scenario, transmitted signal usually received at receiving end with reduced signal strength, which is cause of deep fade. However, in Rayleigh fading channel, huge number signals or waves are scattered, reflected, independently and identically distributed. Therefore, this kind of channel is more important in real wireless networks [33],[35]. The envelope of Rayleigh fading channel obeys statistical Rayleigh distribution, the probability density function of Rayleigh fading channel can be expressed as follows [28],

$$f(x) = \frac{x}{\sigma^2}\exp\left(-\frac{x^2}{2\sigma^2}\right), x \geq 0 \tag{1}$$

The Rayleigh distribution is a stationary Gaussian distribution with 0 mean and σ^2 variance.

2.2.2.2 TDL channel

5G is the latest generation of wireless techonogy has been included commercially in telecommunication system with higher data rates, low latency, and higher capacity than the prevailing 4G technologies. However, according to the 3rd Generation Partnership Project (3GPP) released report the 5G communication system expected frequency range will be from 0.5 to 100 GHz. Based on the radio environments, there are five different types of TDL channel models are currently being deployed industrially for 5G networks, among them existing TDL-A, TDL-B and TDL-C channel model are designed for NLOS scenario, whereas TDL-E and TDL-D are for LOS environment. Figure 3 depicts the actual scenario of TDL channel in multipath propagation radio signal environment. The channel impulse response for TDL multipath channel with N paths can be defined as [35],

$$h(t,\tau) = \sum_{k=1}^{N} \alpha_k(t)\delta(\tau - \tau_k) \tag{2}$$

where, $\alpha_k(t)$ is the overall amplitude at the τ_k delay for the k^{th} paths.

According to the Jacks spectrum, the maximum Doppler shift (f_D) can be written as,

$$f_D = \frac{|\bar{V}|}{\lambda_0} \tag{3}$$

To meet the desired root means square (RMS) delay following equation (4) can be used.

$$\tau_{n,scaled} = \tau_{n,model}.DS_{desired} \tag{4}$$

Where, $\tau_{n,model}$ is normalized delays of n^{th} taps of TDL,

$DS_{desired}$ is desired or expected delay (ns),

$\tau_{n,scaled}$ is newly generated delays (ns) for n^{th} taps or paths.

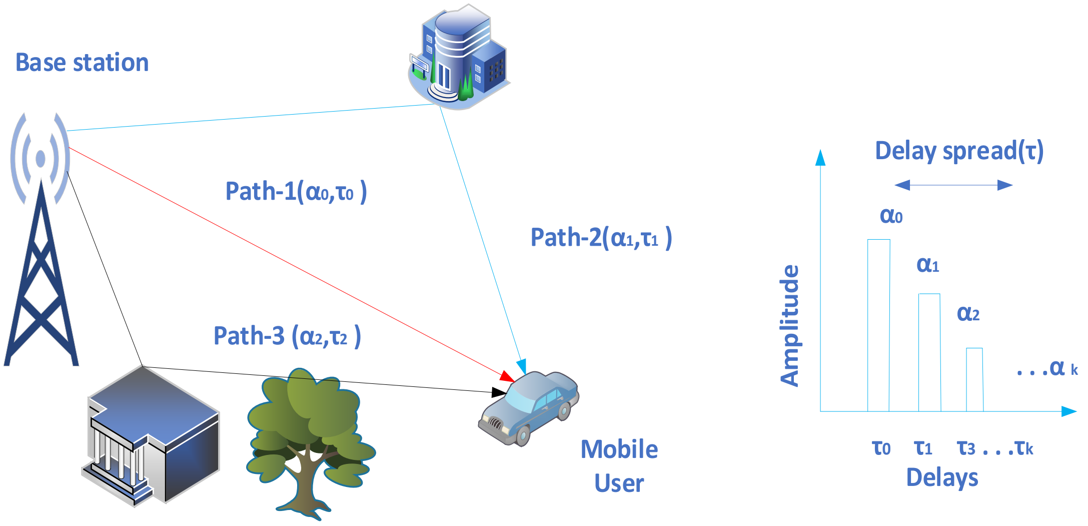


Figure 3. *Radio signal propagation in TDL channel*

2.3 OFDM signal

The OFDM is a multicarrier technique which capable of providing highly efficient bandwidth usage by splitting the whole bandwith spectrum into multiple subgroups, each subgroup is modulated with different subcarriers [36]. OFDM is completely different from the conventional single carrier modulation technique. In comparism, conventional single carrier modulation techniques are drastically affected by ISI, whereas OFDM has strong and powerful immunity against ISI due to the exploitation of longer CP duration. In multicarrier technique, each subcarrier is separated from each other that means does not have influence on each other. However, the orthogonality between the adjacent subcarriers depend on specific choice of subcarrier spacing. Figure 4 shows OFDM signal spectrum in the transmission side where subcarriers are orthogonal to each other but from the sidelobes specific time instant can be found. Once we get the time domain symbol duration subcarrier spacing can be determined via $\Delta f = \frac{1}{T_u}$, where T_u is the symbol duration [37].

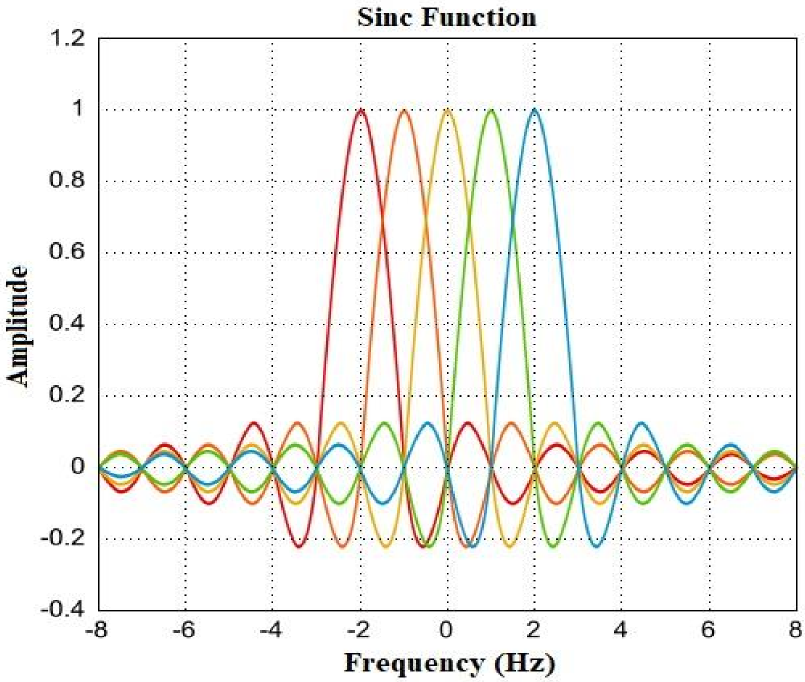


Figure 4. *OFDM signal spectrum*

2.4 OFDM transmitter and receiver

The implementation method of OFDM system has been described block by block to depict the actual scenario for OFDM communication shown in Figure 7. First binary input information bits ($A_{0,}A_{1,}A_2, . . . A_n$) and pilot bits ($B_{0,}B_1, B_2, . . . B_m$) are generated randomly, then converted to complex symbols separately using different digital modulation schemes, for example, BPSK, QPSK, QAM modulation techniques and so on. These are the most common types of modulation schemes used for digital data transmission. For instance, QPSK modulation technique that converts binary bits into symbol, actually it transmits two bits per symbol. A QPSK symbol does not represent 0 or 1 like amplitude shift keying(ASK) and frequency shift keying(FSK), it represents the symbol in constellation point from of $00, 01, 10$ or 11 [38]. The constellation point for QPSK modulation technique shown in Figure 5.

The pilot symbols are used only for channel estimation purposes not for conveying information data. However, once both the information and pilot bits are converted to complex symbols, and then added together to generate OFDM frame [38]. To perform OFDM modulation, symbols are mapped to active subcarriers and the rest of the subcarriers are padded with zero, this process is simply called OFDM modulation [38].

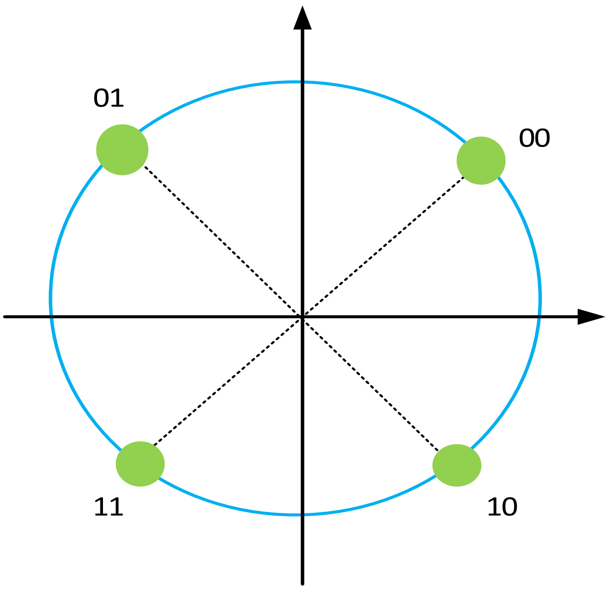


Figure 5. *Constellation points for QPSK modulation technique(* A_k *is any of the points in the constellation*)

These OFDM modulated signals are fed to the Inverse Fast Fourier Transform (IFFT) block for converting frequency domain to time domain to prepare for transmission. Then right after IFFT operation, all the time domain signals are summed together and can be expressed mathmatically as follows,

$$x(t) = \sum_{k=0}^{N_c-1} A_k^{(m)} e^{j2\pi k\Delta f t} \tag{5}$$

Where, N_c is the number of subcarriers, k is subcarrier index, $A_k^{(m)}$ is symbol at k^{th} subcarriers and m^{th} OFDM symbol and Δf is subcarrier spacing [38]. Before transmitting OFDM signal, CP is added to each incoming symbol and it also extends the length (T_{symbol}+T_{cp}) of the OFDM symbols. It is a cyclic process, CP is copied from the last part of the symbols and appended to the fronts. The process of CP addition with information symbols has been depicted explicitly in Figure 6. The reason behind adding CP is to save the information symbols from interference. Once signal converted parallel to serial CP is added to each symbol for transmitting through the wireless channel [38].

Generally, the receiver is the reverse process of transmitter. The receiver receives signal in the form of serial data. Reciever first performs CP extraction process and then converts incomming serial signal to parallel for Fast Fourier Transform (FFT) operation. After performing FFT and extraction of zero padding operation signals are fed to channel estimation and channel equalization block to eliminate the effect of the multipath propagation [38].

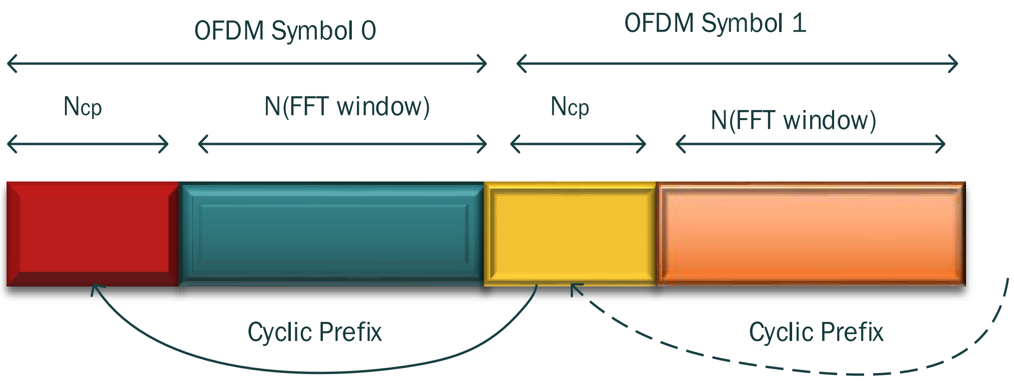


Figure 6. *Cyclic prefix insertion in OFDM symbols*

The functionality of channel estimation block can be represented mathmatically by following equation,

$$\boldsymbol{H_c}\,(k) = \frac{\boldsymbol{Y}(k)}{\boldsymbol{X}(k)} \qquad \mathrm{k} = 0{,}1\,.\,.\,.N_c - 1 \tag{6}$$

Where, $\boldsymbol{H_c}(k)$ is estimated channel by channel estimated block, $\boldsymbol{Y}(k)$ is transmitted symbols, and $\boldsymbol{X}(k)$ is pilot symbols. Pilot symbols do not carry any information data, they are uesd only for assisting the receiver for estimation the parameters. Immediate after equalization and channel estimation, signals are converted parallel to serial, and finally, using different demodulator schemes signals are demodulated to get back the original information bit streams [38].

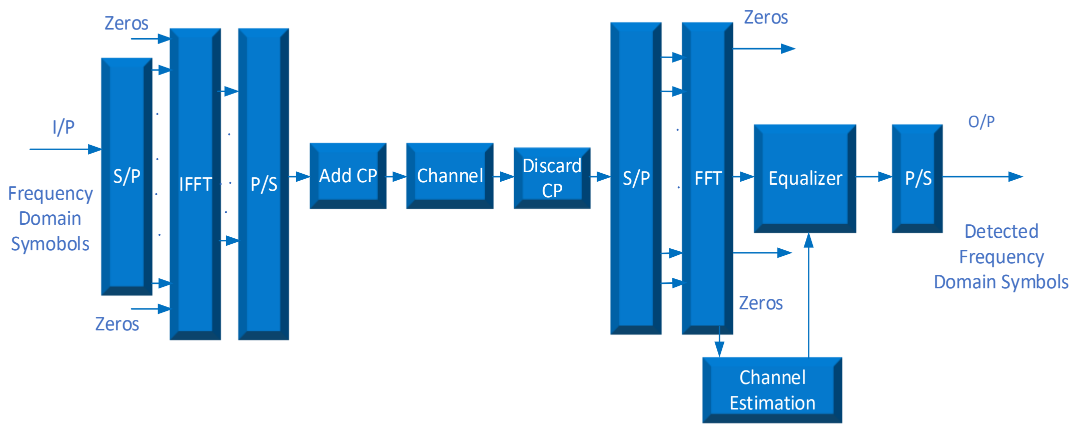


Figure 7. *Transmitter and receiver structure of OFDM system*

2.5 Summary

The huge distinctive features make OFDM system superior over a conventional single carrier transmission technique. The major advantage of OFDM communication is orthogonality between adjacent subcarriers and robustness against ISI due to use of CP [39]. Another advantage of OFDM system over conventional single carrier technique is powerful resistant to the frequency selective fading and robustness against the narrow band interference[40]. Of course in OFDM system, ICI is a major cumbersome against high data transmission, but it is also possible to mitigate this inconvanience by using different types ICI cancellation techniques high spectral efficiency can be achieved by keeping orthogonality between the adjacent subcarriers [41]. OFDM system allows multiple users to use multiple subcarriers which increases multiple accessibility for wireless communication [42]. OFDM system has few drawbacks beside it's beneficial aspects. As OFDM system usually exploits longer CP duration than the channel delay spread to supress ISI in multipath environment, it occupies a large amount of time duration which can not be used to communicate data. CP is usually used for prectecting information symbols from intereference. Furthermore, it also cause of more power consumption since the OFDM frames consist of both the CP duration(t_{cp}) and symbol duration(t_s) [43]. Although OFDM system capable of acheiving high mobilities, high data rates, and overall spectrum efficiency, but it may experience time and frequency selective fading. However, this system is also highly sensetive to doppler shift, due to doppler shift ICI introduces, consequently data transmission rate and overall performance degrade [44].

3. PERFORMANCE OF OFDM IN COMMUNICATION

3.1 Simulation settings

3.1.1 Simulation parameters

Prefering the appropriate parameters is an important factor for any kind of investigation performed by programming simulation process. In this scope, we investigated performance of OFDM communication system in MATLAB simulation based on wide varity of parameter combinations. However, we revealed here the basic parameters, for instance, noise, modulation techniques, and CPs are used in simulation for performance assessment.

3.1.2 Noise

During the simulation process AWGN has been added with received signals. Nosie, basically unwanted signal that interferes with data signal and intends to create disturbance in transmission as well as overall communication system. AWGN follows two properties, firstly, white noise has constant power spectral density over all the frequency band, and can mathematically be expressed as follows [45],

$$w(f) = \frac{N_0}{2}(-\infty < f < \infty) \tag{7}$$

Second property, AWGN obeys the Gaussian distribution also known as Normal distribution. Normal distribution can be denoted as $x \sim N(\mu, \sigma^2)$, where μ is expectation and σ is variance. The probability density function can be written as below [46],

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left\{-\frac{(x-\mu)^2}{2\pi^2}\right\} \text{for } -\infty < x < \infty \tag{8}$$

AWGN is the most common and well-known noise that has been used widely in communication for research and development purposes. Theoretically it is capable of properly depicting the real noise condition in wireless transmission system.

3.1.3 Modulation techniques

Because of the growing demand for higher data rates, nowadays, higher QAM orders have become a considerable aspect in wireless communication [47]. The performance of OFDM communication profoundly depends on the proper choice of modulation techniques. However, in our simulation, we deployed binary phase shift keying (BPSK) modulation scheme for modulating pilot symbols and QPSK, 16QAM, 64QAM, 256QAM for information symbols. The idea behind this choice is to transmit more information bits and less pilot bits, since pilot symbols are soley used for assisting the channel estimation process. Furthermore, lower order modulation schemes always perform better channel estimation result than the higher orders.

3.1.4 Cyclic prefix

The CP plays an important to resist ISI caused by multipath propagation in OFDM communication system by protecting the information symbols from ISI [48] [30]. In case of time verying channel condition, however, it is better to adapt variable CP lengths rather than fixed CP for effective high speed wireless communication system [49]. In order to scrutinize the performance of OFDM system over AWGN and Rayleigh fading channel, we deployed different CP lengths, for instance, 0% (CP0), 25% (CP4), 12.5% (CP8), 8.34% (CP12) and in some circumstances 6.25% (CP16) of symbol duration also has been utilized in simulation process.

3.1.5 Performance metric

The BER is the most basic and common scaling factor is used for the assessment of communication quality. BER can be defined as the probability of number error bits per bit transmitted. On the other hand, SNR is strongly related with BER. However, SNR is the relative power of noise compared to the signal. Due to the comparison simplicity, BER against the SNR has become the most popular criterion among the researchers and industries [50]. BER can be calculated by following formula,

$$BER = \frac{Error}{Total\ number\ of\ bits} \tag{9}$$

For obtaining better BER performance high SNR is required. On the other hand, low SNR produces high BER. The low BER has a smaller number of error bits probability at receiver and can be said that the performance is high, on the other hand, high BER causes of low performance of communication system [51].

3.2 Simulation results and analysis

3.2.1 BER performance analysis of OFDM system in AWGN

In this sub section, we started with investigating the performance of OFDM system by deploying AWGN channel model. The basic simulation parameters have been given in following Table 1. Based on these parameters in Table 1, next several simulation results have carried out for analysing purpose and figured out which parameter combination highly suitable with transmission process in wireless communication regarding AWGN channel.

Table 1. *Parameters used in AWGN channel*

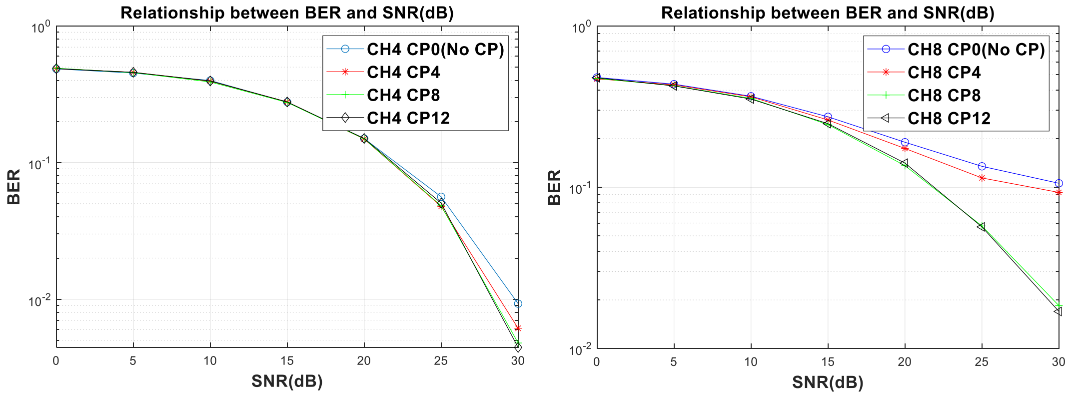
System parameters	Specifications
Channel model	AWGN
Active subcarriers/FFT size	20/32
Modulation order of pilot symbols	BPSK
Subcarrier spacing (KHz)	15
Number of information/pilot symbols	20/20
Cyclic prefix (CP)	0%(CP0), 25%(CP4), 12.5%(CP8), 8.34%(CP12) and 6.25%(CP16) of symbol duration
Modulation order of information symbol	QPSK, QAM16, QAM64, QAM256

3.2.1.1 BER VS SNR for varying CP, channel length and QAM orders combination

For investigating the performance of OFDM system in wireless communication, we used BER against SNR range as a performance metric. Basically the system performance of any communication system closely depends on the BER. Therefore, we assessed the performance by plotting BER vs SNR curve varying different parameters combination in next simulations under this sub section.

(a) Fixed channel length with variable CP lengths (CP0/CP4/CP8/CP12)

Figure 8(a) contains four different line graphs are representing performance of various CP lengths CP0 (No CP), CP4, CP8 and CP12 with fixed channel length 4 over OFDM system in AWGN channel. According to the mentioned Figure, CP12 achieved minimum BER with high SNR compare to the others, whereas CP0 has the worst BER performance among all. It was noticed that with the increment of CP lengths, the performance of BER curve was gradually improving. For further investigation, we changed only the channel length 4 to 8 and kept other parameters constant in simulation and the resultant output shown in figure 8(b). Due to the change in channel length, the output changed visibly. After scrutinizing the BER vs SNR curve, it was noticed that the BER performance for CP12 was the highest and for CP0 was the lowest. In comparison, CP8 holding the second position and the last position holder was CP0 according to the BER performance curve regarding the SNR range. From the both observations, it is obvious that comparatively longer CP improves the BER performance of OFDM system in multipath communication as longer CP more compatible aginst the ISI than CP less system or with shorter CP.



(a) (b)

Figure 8. *Performance over variable CP lengths in AWGN channel*

(b) Different channel length(4/8/12/16) with variable CP (CP0/CP4/CP8/CP12)

In previous section, we investigated the performance of OFDM system based on variable CP lengths with fixed channel length combination. For this experimental observation, we increased the channel length sequentially high combining with variable CP lengths, at the same time all other parameters have been kept constant. Figure 9 shows the BER performance of OFDM system over AWGN channel based on different channel lengths with variable CP lengths.

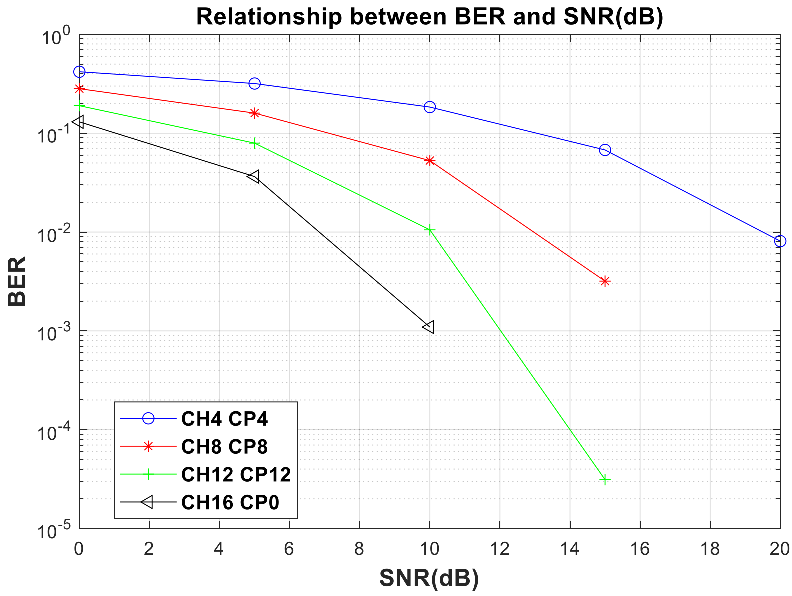


Figure 9. *BER performance over variable channel and CP lengths*

According to the Figure 9, the BER performance was noticed high for the combination of channel length 12 with CP12 by achieving maximum SNR. On the other hand, though the BER for the combination of channel length 16 with CP0 was minimum but the SNR was noticeably high. So, we cannot say it is a better combination for wireless transmission. However, rest of the combinations of channel lengths and CPs were moderate performers.

(c) Fixed channel and CP length with different QAM orders (4/16/64/256)

In this specific simulation, we investigated the performance of OFDM system based on the QAM schemes by keeping constant channel length and CP length. In digital communication, for modulating signal various kinds of modulation techniques are used, QAM scheme is one of them. Basically, the QPSK and QAM schemes 16, 64, 256 have been used for this investigation.

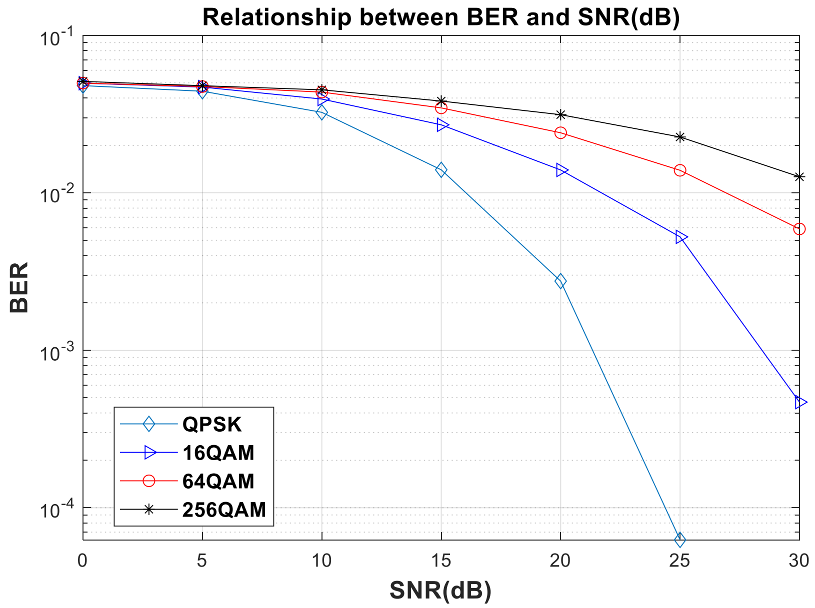


Figure 10. *BER performance over different QAM orders in AWGN Channel*

The resultant Figure 10 indicates the BER performance of QPSK is higher than the other QAM order schemes. The QPSK was the dominating modulation technique in the graph by achieving minimum BER and the highest SNR. On the other hand, the performance of 256QAM is very low in comparison. But it was also noticed that with the increment of QAM orders, the BER performance was seen in the descending trend. However, the reason behind this, the higher order modulation schemes provide more points on the constellation and transmit more bits per symbol. The drawback of the higher order QAM technique is the points on the constellation are too closer and more noise sensitive. As a repercussion performance degrades.

3.3 BER Performance of OFDM system in Rayleigh fading

We started the MATLAB simulation with assessing the BER performance of OFDM system with different parameters combination in AWGN channel. For further investigation, Rayleigh fading channel has been depolyed in simulation to explore out the performance of OFDM system with differenet parameter combinations in this section. The simulation parameters those have been adapted with Rayleigh fading are given in following Table 2.

Table 2. *Parameters used in Rayleigh fading channel*

System parameters	**Specifications**
Channel model	Rayleigh fading
Active subcarriers/FFT size	20/32
Modulation order of pilot symbols	BPSK
Subcarrier spacing (KHz)	15
Number of information/pilot symbols	20/20
Cyclic prefix (CP)	0%(CP0), 25%(CP4), 12.5%(CP8), 8.34%(CP12) and 6.25%(CP16) of symbol duration
Modulation order of information symbol	QPSK, QAM16, QAM64, QAM256

3.3.1 BER VS SNR for varying CP, channel length and QAM order combination

The same craiteriaon have been also applied to expose the performance of OFDM system in Rayleigh fadding channel too. We expounded and compared the BER vs SNR curve in next steps to scritinize the performance.

(a) Fixed channel length and QAM orders with CP length (CP0/CP4/CP8/CP16)

For evaluating the BER performance of OFDM system based on variable CP lengths, we kept all other parameters fixed, such as channel length 8 and modulation order 16QAM and so on. We employed four different CP lengths CP0, CP4, CP8 and CP16 respectively. Figure 11 shows that the higher CP lengths were performing better than the lower. The CP4 achieved the minimum BER at SNR 50dB. On the contrary, the CP16 provided high BER and very worse result was also seen in respect to SNR. Hence it can be finalized with this statement that CP4 was the higher BER performer and CP16 was lower. So, we can assert from this observation that for smooth communication longer CP length is highly required.

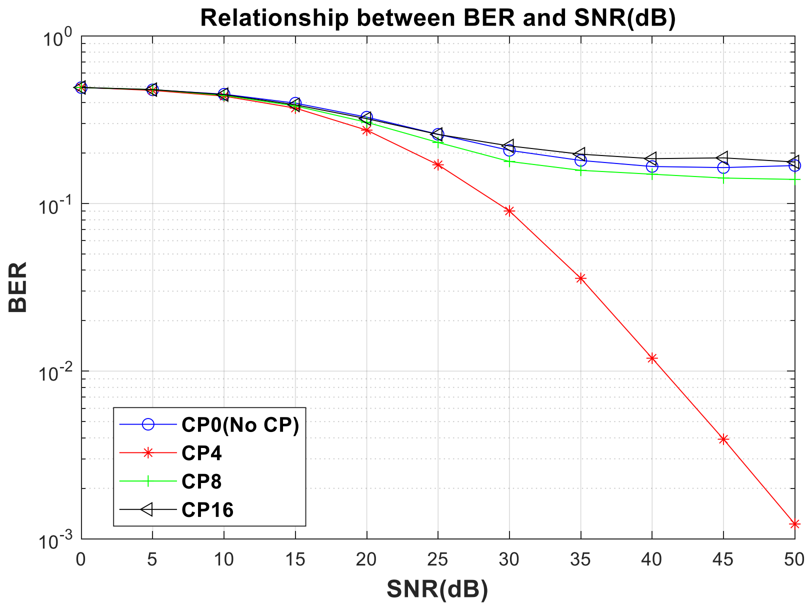


Figure 11. *BER performance over variable CP lengths in Rayleigh fading channel*

(b) Fixed channel and CP lengths with different QAM orders(4/16/64/256)

To observe the BER performance of OFDM system over various QAM schemes, we generated randomly channel coefficient based on statistical Rayleigh distribution, also kept constant both the channel and CP length, and simulated with different QAM schemes result shown in Figure 12.

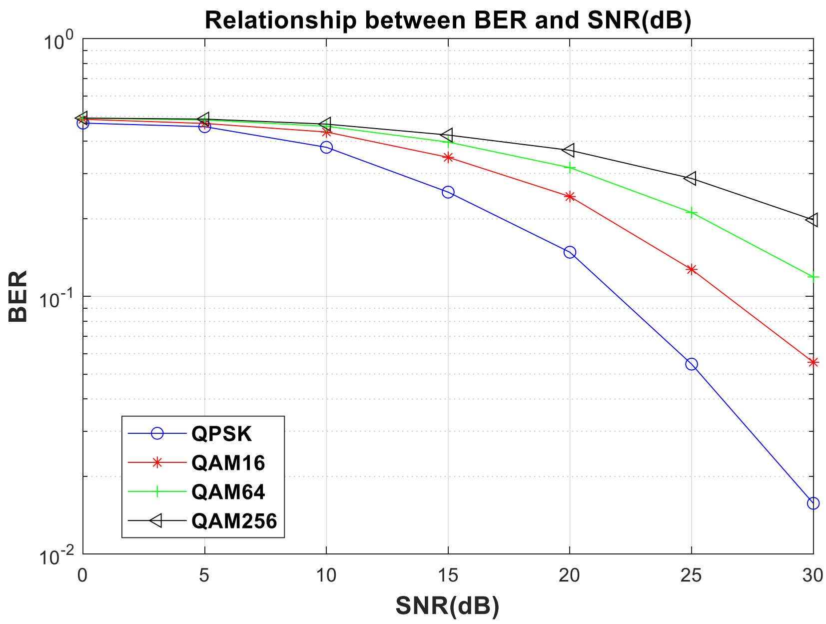


Figure 12. *BER performance over different QAM orders in Rayleigh fading channel*

We deployed different QAM orders to observe the performance of the BER vs SNR curve. The figure indicates that the modulation scheme QPSK ($M = 4$) achieved the high SNR with minimum BER which showed better in performance. Sequentially, 16QAM showed comparatively low performance and 64QAM was the third position holder in terms of BER performance. In comparison, the performance of QPSK was high and the lowest for 256QAM. Hence in terms of BER performance lower order modulation techniques are better than higher orders.

(c) Fixed CP length with QAM orders(4/16/64/256) in Complex channel

In previous sections, we figured out the performance of OFDM system based on different parameters combination in Rayleigh fadding channel. In this step we changed channel model Rayleigh fading to Rayleigh fadding complex channel. For this spacific simulation we exploited all the parameters from Table 2 except the channel. We exploited Rayleigh fading complex channel.

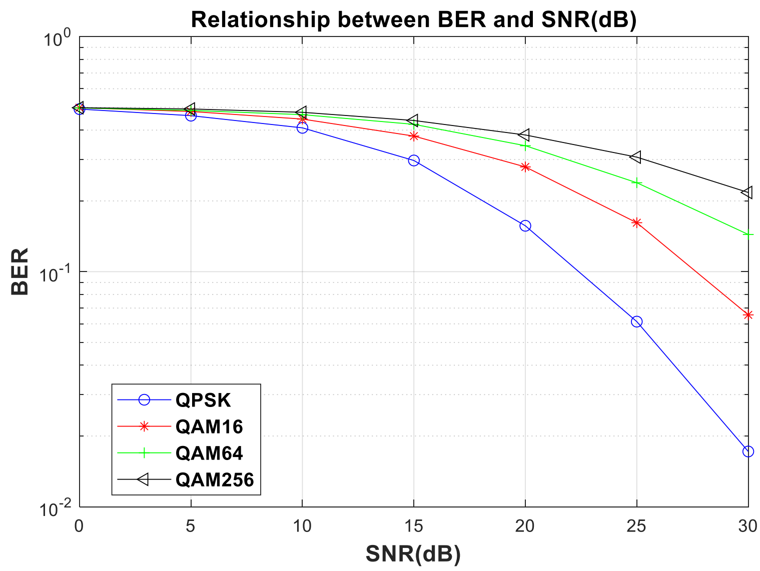


Figure 13. *BER performance over different QAM orders in complex channel*

Therefore, we followed statistical Rayleigh distribution for generating amplitude and the phase uniformly distributed 0 to 2π radian for Rayleigh fading complex channel. For testing the BER performance over fixed CP length with different QAM orders, all other parameters have been also kept fixed. The simulation result shows in Figure 13. After deeply observing the resultant Figure, the BER performance curve of QPSK modulation technique was the best due to the minimum BER whereas, the performance curve of 256QAM was seen very poor. On the contrary, the BER performance for 16QAM and 64-QAM were moderate between the highest and lowest.

So, it can be concluded that lower QAM orders return high BER performance than the higher QAM. The fact that the lower QAM orders usually perform better because of less noise sensitivity.

3.3.2 BER performance analysis of OFDM system in TDL-A

The aim of the section is to investigate the performance of OFDM system based on variable CP lengths over TDL-A channel model with $1000\ ns$ RMS channel delay spread. The parameters in following Table 3 have been adapted in simulation for analyzing process. However, in order to distinguish the multipath effects, we have preferred very high and low CP durations than the maximum channel delay spread (MCDS).

Table 3. *Simulation parameters used in TDL-A channel*

System parameters	Specifications
Channel model	TDL-A, zero mobility ($\boldsymbol{f_D} = 0$),$1000ns$ RMS delay spread
Active subcarriers/FFT size	64/256
Modulation order of pilot symbols	BPSK
Modulation order of Information symbols	QPSK
Subcarrier spacing (KHz)	15
Number of information/ pilot symbols	15/15
CP lengths	CP4, CP20, CP40, CP70

The Figure 14 shows the BER performance for different CP lengths in TDL-A $1000\ ns$ where MCDS is about $1.07\mu s$.

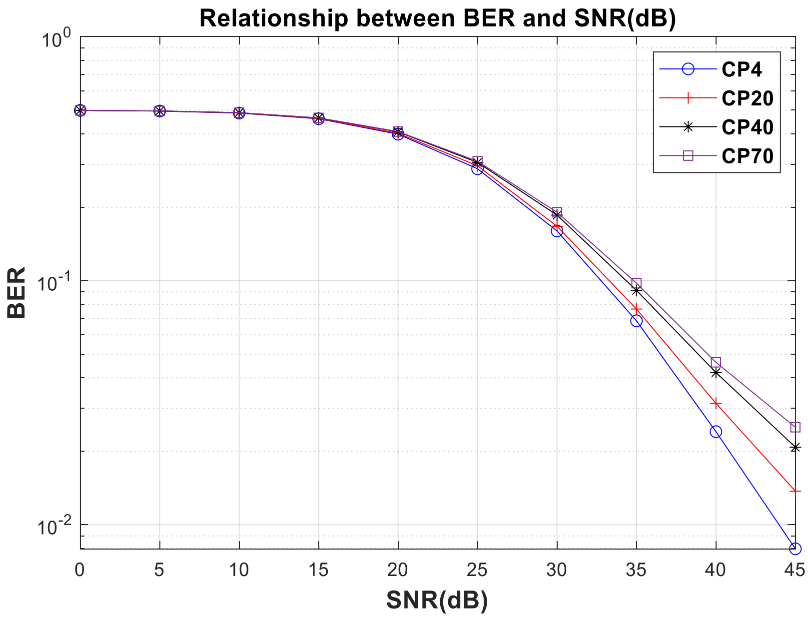


Figure 14. *BER performance with variable CP lengths over TDL-A channel*

The different CP lengths CP4(about $1.34\ \mu s$), CP20(about $0.026\ \mu s$), CP40(about $0.013\ \mu s$) and CP70(about $0.007\ \mu s$) have been used here for investigation purpose.

According to the resultant Figure 14, it is visible that with the decrement of CP duration the BER performance degraded proportionally. This is because of ISI; hence the CP lengths should be long enough compared to the MCDS for eliminating the ISI and at the same time the required transmit power need to be more enough for maintaining the same BER.

In comparison, the BER performance for CP4 was maximum as the duration is well higher than the MCDS, on the other hand, the performance CP70 was the lowest since the duration is well below than the MCDS. The fact that the CP4 is long enough to resist the ISI, whereas the duration of CP70 is comparatively too short and unable to combat ISI. Hence it is strongly proven by this simulation that the importance of CP length is vital to suppress ISI in multipath radio propagation.

3.4 Conclusion

In first part of this thesis, we have simulated in MATLAB programming for investigating BER performance in OFDM system using different channel models such as AWGN, Rayleigh fading, Rayleigh fading Complex and TDL-A with different parameters combination. We exploited different CP lengths, QAM orders, and variable channel lengths for analyzing the performance of different CP lengths and different QAM orders.

Firstly, we deployed the AWGN channel model with variable CP lengths and different channel lengths and found that the lower channel lengths with longer CP lengths provide the better BER performance. In case of modulation orders, lower order (QPSK) performed high BER performance than the higher QAM in all steps of our MATLAB simulation.

Secondly, Rayleigh fading and Complex channel, the same criterion has been also applied to demonest the performance of variable CP lengths, different QAM orders in terms of BER. In this case the same result was found as in AWGN channel.

Thirdly, we also tested the performance of different CP lengths in TDL-A channel, and our findings were very fruitful to prove that longer CP is strong enough to resist ISI, whereas shorter CP lengths inefficient to combat ISI.

We can sum up with this statement that CP lengths must be at least equal or longer than the channel lengths for achieving better BER performance in multipath radio propagation scenario. In case of testing BER performance for different QAM orders, lower order QAM provides the best BER result than the higher.

3.5 Future recommendation

Due to the proliferation of information technology wireless communication is upgrading with a high-speed development trend. Consequently, this sector is becoming more wider day by day only because of the endeavours of the thousands of researchers all over the world. As a part of this trend, we invested little efforts to assess the communication performance in OFDM system over different parameters by this work. However, due to shortage of time there are remaining many aspects those have not been taken in account in our works, those are as follows:

- We have adapted four different types of channel models, for example, AWGN, Rayleigh fading channel, complex channel, and TDL-A channel in MATLAB simulation. However, the other channel models such as Rician, Nakagami, TDL-B, TDL-C, TDL-E can be tested in future by applying the same procedure.
- In our study, we explored out performance of QAM schemes, and found that lower QAM performs better than the higher since they are less noise sensitive. As we already know that the lower QAM transmits less bits compare to higher QAM. Further study can be done for exploiting higher QAM to achieve high data with smooth transmission over OFDM system.

We have seen the higher CP lengths contribute high BER performance in OFDM communication but the downside of using longer CP is high power consumption. Unfortunately, we have not worked on that aspect. A further research can be started with aiming the reduction of CP lengths as much as possible for keeping the system performance constant. Therefore, this is an important factor regarding power consumption since the mobile devices usually survive with low power.

4. OFDM SIGNALS FOR RANGING

4.1 Introduction of MUSIC

The term MUSIC stands for Multiple Signal Classification is a technique used to estimate the parameters of multiple signals incoming at an antenna array based on the measurement of received signals at array elements. The MUSIC algorithm can be applied especially for unbiased DOA and TOA estimation, the estimation of multiple frequency, the number of signals, and so on [52].

The sub-space characteristics structure based high resolution MUSIC algorithm was first proposed by Schmit [53]. MUSIC offers super resolution and less computational complexity [54]. It is a method of eigen decomposition of covariance matrix divided into two subspaces, noise subspace and signal subspace. Utilizing these two subspaces DOA can be estimated with high precision [55], [56]. Although the estimation performance of MUSIC is high precision, but it is also inevitably affected by several factors, for example, the number of array elements, array element spacings, the number of sample snapshots, and SNR etc. Unfortunately, because of unstable array elements spacing algorithm might provide false peaks. Therefore, it is important to emphasis on array element spacing in the estimation process for the sake of high accuracy. In modern signal processing, array signal processing has become more popular as well as dominating part among the research areas, for achieving the rapid improvement in different fields recently [53]. However, MUSIC spatial spectrum estimation is an important brunches of array signal processing has been widely applied in radar communications, sonar and, also this technology being exploited earthquakes forecasting [53], [57], [58].

4.2 MUSIC in DOA

The enormous demands for super-resolution DOA estimation for arriving signal at antenna array tremendously increasing day by day for the sake of quality improvement in radar communications and navigation systems. There are many techniques have been proposed beforehand regarding DOA estimation including MUSIC algorithm, the Coupon method, Estimation of Signal Parameters Via Rotation Invariance Technique (ESPRIT). Among them MUSIC is the most fundamental and comparetively popular technique which capable of ensuring super-resolution DOA estimation performance [59]. In this thesis work, a comprehensive simulation analysis and scrutinization on MUSIC have been performed in following sections.

4.2.1 Signal model

Let us consider, uniform linear array (ULA) with M elements(Figure 15), the distance between two adjacent elements d is $\lambda / 2$ [60], D is the number of wavefronts arrived at M array elements where M array elements are linear combination of signal and noise ($D < M$).

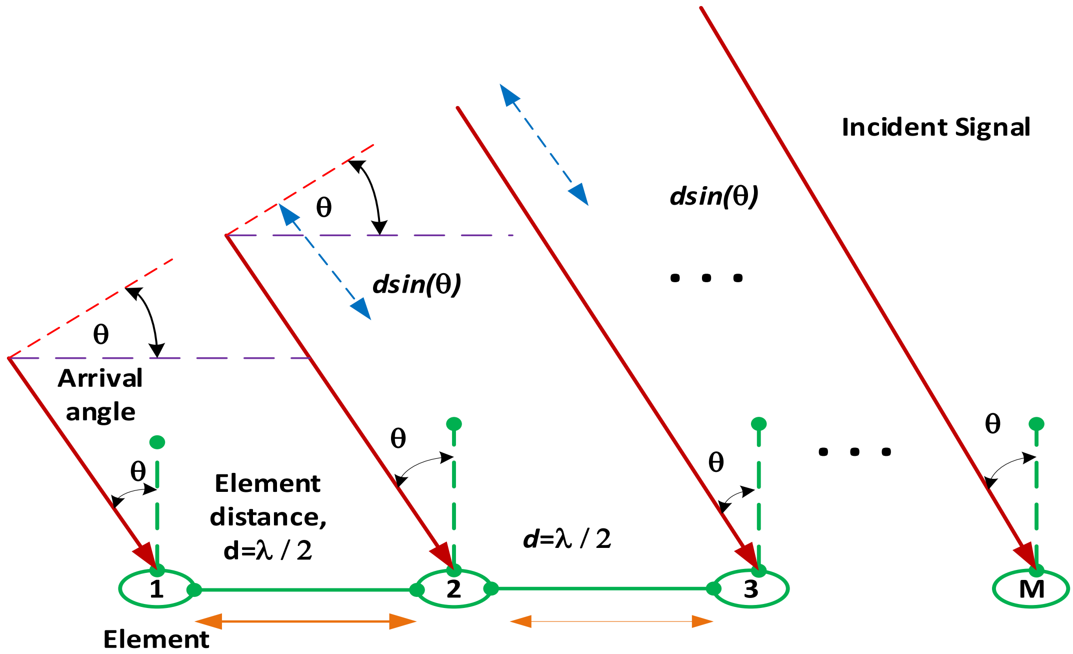


Figure 15. *Uniform linear antenna array with M elements*

In this way, the multiple signal classification is used for estimating various parameters of arrival signals with following approach [52],

$$\begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ X_M \end{bmatrix} = [\boldsymbol{a}(\theta_1)\ \ \boldsymbol{a}(\theta_2)\ \ \boldsymbol{a}(\theta_3) \ldots\ldots\ldots \boldsymbol{a}(\theta_D)] \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ F_D \end{bmatrix} + \begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ N_M \end{bmatrix} \tag{10}$$

The equation (10) can be expressed as simplified form,

$$\boldsymbol{X} = \boldsymbol{AF} + \boldsymbol{N} \tag{11}$$

Where, $\boldsymbol{X}$ is the vector of received signal at array elements M, which is $M \times 1$, $\boldsymbol{F}$ is complex quantity which represents the incident signals size is $D \times 1$. $\boldsymbol{N}$ is additive white Gaussian noise (AWGN) vector with a zero mean and variance $\sigma^2 = 1$.The dimension size of noise vector $\boldsymbol{N}$ is $M \times 1$. Generally, the vector $\boldsymbol{X}$ and $\boldsymbol{A}$ are in the form of complex. At the same time, the noise vector $\boldsymbol{N}$ is also a complex format.

$\boldsymbol{A} = [\boldsymbol{a}(\theta_1)\ \boldsymbol{a}(\theta_2)\ \boldsymbol{a}(\theta_3) \ldots\ldots\ldots \boldsymbol{a}(\theta_D)]$ is a matrix of D steering vector size $M \times D$, steering vector for each target signal can be individually written as follows,

$$\boldsymbol{a}(\theta) = \begin{bmatrix} 1 \\ e^{(-j\pi sin\theta)} \\ e^{(-j2\pi sin\theta)} \\ \cdot \\ \cdot \\ \cdot \\ e^{(-J(M-1)\pi sin\theta)} \end{bmatrix} \quad (12)$$

4.2.2 DOA estimation algorithm

MUSIC is an excellent algorithm which used to find direction of radio signals arriving at antenna array [59], For estimating DOA by exploiting MUSIC, first of all need to consider the input of this algorithm. Depending on the number of array elements M, the receiver constructs covariance matrix $M \times M$ as an input of the algorithm. However, the basic prerequisition for performing DOA estimation in MUSIC is the covariance matrix $\boldsymbol{R_{xx}}$ which must be square matrix ($M \times M$) and vector $\boldsymbol{X}$ should be confined in the space range of vector $\boldsymbol{A}$. MUSIC basically uses noise subspace and signal subspace to reconstruct the spatial spectrum function, afterward DOA can be estimated by searching the spectrum peaks. The functional block diagram of DOA estimation process has been shown in Figure 16. In this section, the DOA estimation method is explained in detail for uncorrelated radio signals step by step as follows [61]:

Step 1. From the array output $\boldsymbol{X}$, the covariance matrix $\boldsymbol{R_{xx}}$ can be calculated as follows,

$$\boldsymbol{R_{xx}} = E[\boldsymbol{X}\boldsymbol{X}^H] \quad (13)$$

$$\boldsymbol{R_{xx}} = E[(\boldsymbol{AF} + \boldsymbol{N})(\boldsymbol{A}^H\boldsymbol{F}^H + \boldsymbol{N})] \quad (14)$$

Where, E denotes the statistical expectation, H is complex conjugate.

Step 2. According to independence of signal and noise, covariance matrix ($\boldsymbol{R_{xx}}$) can be decomposed into two subspaces, signal subspace and noise subspace. And then applied eigen decomposition for finding eigen values and eigen vectors. The covariance matrix, $\boldsymbol{R_{xx}}$ can be written as follows,

$$\boldsymbol{R_{xx}} = \boldsymbol{A}\boldsymbol{R}_{FF}\boldsymbol{A}^H + \boldsymbol{R}_{NN} \quad (15)$$

Where, $\boldsymbol{A}$ is $M \times D$ dimensional matrix associate with the number of sources signal, and $\boldsymbol{R_{NN}}$ is a matrix associated with noise containing dimension $M \times 1$.

Let us obtain,

$\mathbf{\Lambda} = diag(\lambda_1, \lambda_2 \dots \lambda_M)$ is the diagonal matrix and $\lambda_1, \lambda_2 \dots \lambda_M$ generated eigen values in descending orders. $\mathbf{e} = (\boldsymbol{e}_1, \boldsymbol{e}_2 \dots \boldsymbol{e}_M)$ is eigenvector associate with eigenvalues M in descending orders also. Where $\boldsymbol{e}_1, \boldsymbol{e}_2 \dots \boldsymbol{e}_M$ are eigen vectors.

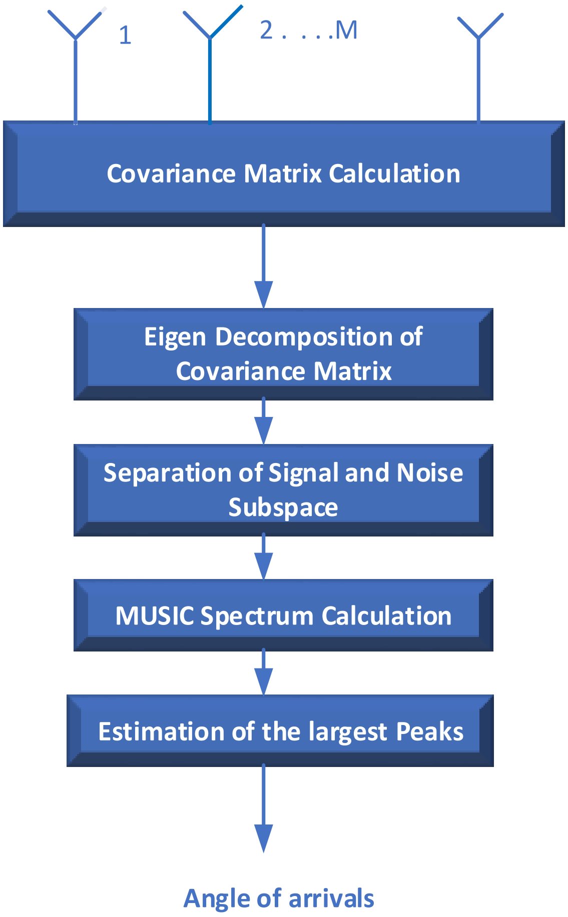


Figure 16. *The functional block diagram of DOA estimation in MUSIC*

Step 3: Once eigenvalues and eigenvectors are calculated, and then estimate the signal subspace $\boldsymbol{E}_S$ and noise subspace $\boldsymbol{E}_N$. The calculated eigenvalues and eigenvector which are equal to the number of signal D, take those large values from the first as a part of the signal subspace $\boldsymbol{E}_S$, the rest of the eigenvalues and eigenvectors $(M - D)$ as noise subspace $\boldsymbol{E}_N$. Due to each column vector in the matrix $\boldsymbol{A}$ are orthogonal to the noise subspace, which leads to $\boldsymbol{E}_n{}^H \boldsymbol{a}(\theta_i) = 0$, where $i = 1,2, \dots D$.

Step 4: Finally, compute the music spectrum according to the formula,

$$P_{MUSIC}(\theta) = \frac{1}{\boldsymbol{a}(\theta)^* \boldsymbol{E}_N \boldsymbol{E}_N^* \boldsymbol{a}(\theta)} \tag{16}$$

In the presence of noise, the value of the denominator of P_{MUSIC} is literary very little. Therefore, the MUSIC spectrum will appear peaks and find the DOA estimation [62] of incident signals.

4.2.3 Preliminary result of DOA estimation

Let us assume, two incident signals arrival angles 10^0 and 40^0 respectively recognized by MUSIC algorithm. Both the target signals are uncorrelated with each other's, the ideal additive white Gaussian noise has been adapted with simulation. The array element spacing d has been considered as half wavelength of input signal. For more clarification, the simulation parameters are given in Table 4.

Table 4. *Parameters used for DOA estimation in MUSIC*

Parameters	**Specifications**
Arrival angels	10^0 and 40^0
Number of Snapshots (K)	200
Number array elements (M)	20
SNR (dB)	20
Wavelength (λ) in meter	1
Array element Spacing (d)	λ/2

The simulation output of corresponding parameters shown in Figure 17. There are two independent signals in the hypothetical circumstance, by deploying MUSIC algorithm spectrum peaks have been reconstructed shown in Figure 17.

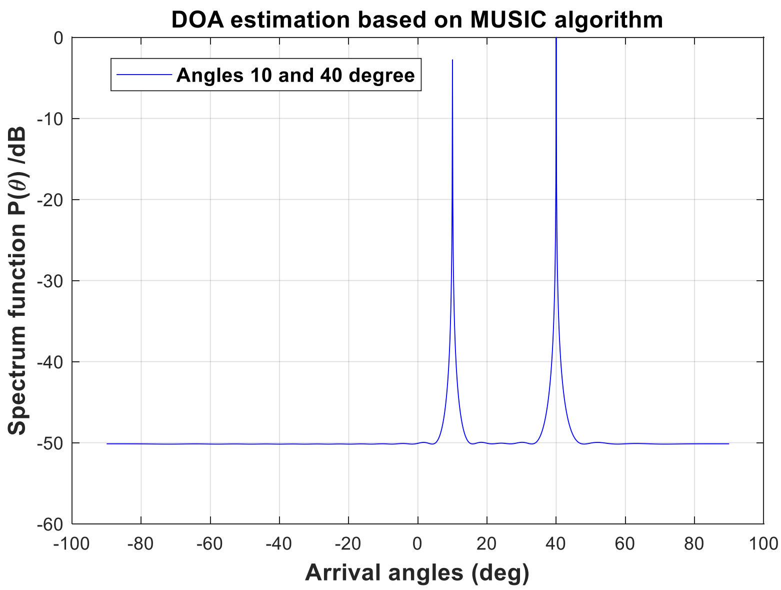


Figure 17. *The Preliminary result of DOA estimation*

However, MUSIC algorithm can be effectively used for estimating the number of incidents as well as the direction of incident signals from independent signal sources.

MUSIC algorithm deals with high precision DOA estimation neglecting traditional shortcomings of multiple signals environment. It is a method that ensures accurate, high resolution and better performance for unbiased DOA estimation. Therefore, the implication of MUSIC algorithm is vast in practical applications.

4.2.4 Effect of parameters on DOA estimation in MUSIC

For both the estimation DOA and TOA, few parameters inevitably have drastic influence on MUSIC algorithm operation. The only application environment and incoming signals are not the major influential factors but also the number of snapshots, SNR, the number of elements, space between the elements blatently affect on the estimation process as well as efficiency [53]. However, in next several subsections, we focused intensively on the basic influencial factors of DOA estimation in MUSIC algorithm.

4.2.4.1 SNR

In this simulation, we investigated how two uncorrelated incident signals recognized by MUSIC algorithm by searching spectrum peaks over different SNR levels. For assessing the performance of MUSIC based on SNR, we adapted the ideal white Gaussian noise with zero mean in this simulation, the number of array elements $M = 20$, element spacing is half wavelength of the incoming signal ($\lambda/2$), the number of snapshots $k = 200$. We kept all of these conditions same and exploited different random value of SNR 20 dB, 0 dB, -20 dB respectively to closely observe the DOA estimation accuracy.

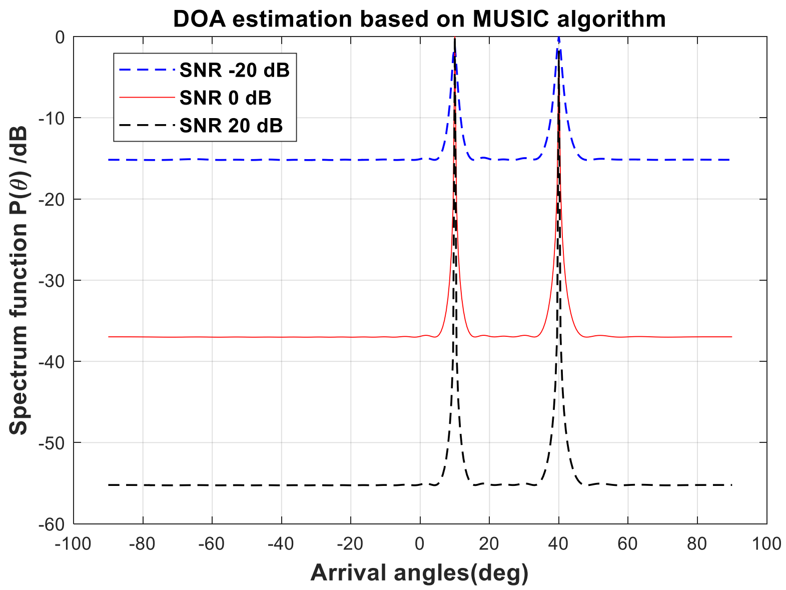


Figure 18. *DOA estimation with different SNR*

The Figure 18 shows the upper dashed line indicated the output for SNR -20 dB, middle solid line for 0 dB, and the lower dashed line 20 dB. In terms of accuracy, the resultant output for SNR 20 dB was high due to the sharp needle peak, whereas the DOA estimation resolution was very poor for SNR -20 dB for it's spectral width beam. Baesd on the output Figure 18, there was seen a noticeable distinctive effect of SNR on DOA estimation performance. Hence, it can be concluded that MUSIC outperforms and provides high resolution DOA estimation at high SNR. On the other hand, the estimation performance sharply declines with the decline of SNR level. The fact that, in low SNR condition signal power is weaker than noise power. On the other hand, in the high SNR condition signal power higher than the noise power. So, it might be a vital research field for the researchers to work on improving the DOA estimation accuracy under low SNR condition.

4.2.4.2 Number of array elements

We exploited almost the same criterion as we did in pervious section to assess the impact of array elements on DOA estimation in MUSIC, here we kept all other parameters same except the number of elements. We assumed three different number of array elements $M = 10$, $M = 50$ and $M = 100$ respectively for this specific purpose. Accordance with these parameters, the simulation result shown in Figure 19.

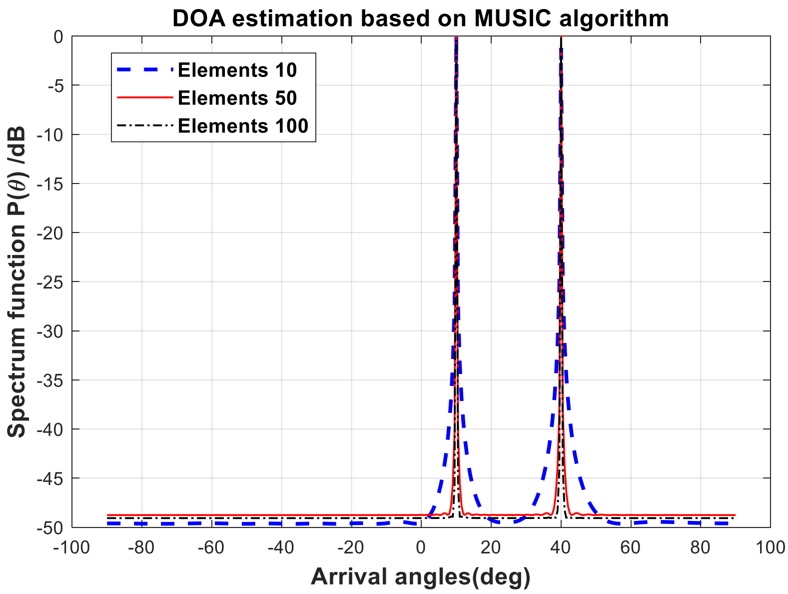


Figure 19. *DOA estimation with different elements*

As can be seen from the Figure 19, there are three lines of spectrum searching peaks. The dashed line represent output for the number of array elements 10, solid line for 50 and dash dotted indicates 100 elements. However, in the contest of accuracy, the dashed line, which was the result of 10 elements with width spectrum beam and performs poor resolution compare to other two spectrum beams. On the contrary, the spectrum beam width for elements 50 and elements 100 was narrower than the elelment 10 and acquired the high resolution. Moreover, the estimation accuracy for elements 50

and 100 are almost the same. Therefore, in practical implementation, the number of elements need to be adapted appropriately according to the circumstantial specifications. Thus, the accuracy of estimation can be meet perfectly according to the demand. By maintaining proper utilization of resources, it is possible to enhance both the speed of operation and efficiency.

4.2.4.3 Number of snapshots

In the last simulation, we have seen how estimation process can be improved based on the number of array elements. In this observation, performance comparison has been performed based on number of sample snapshots in MUSIC regarding DOA estimation . We kept all other parameters same, for example, the number of elements $M = 20$, $SNR = 20$ dB, an array element spacing $d = \lambda/2$ etc. The DOA estimation operation was performed by assuming randomly three different numbers of sample snapshots $K = 20$, $K = 80$ and $K = 500$ respectively for justification the degree of accuracy of MUSIC algorithm depending on the number of snapshots. The simulation result shown in Figure 20. It can be easily conceived that with the increment of the number of sample snapshots the spectrum beam width became narrower and the estimation accuracy gradually increased. Although the large number of snapshots perform better resolution DOA estimation, there might have some computational complexity issues because of the high number of snapshots.

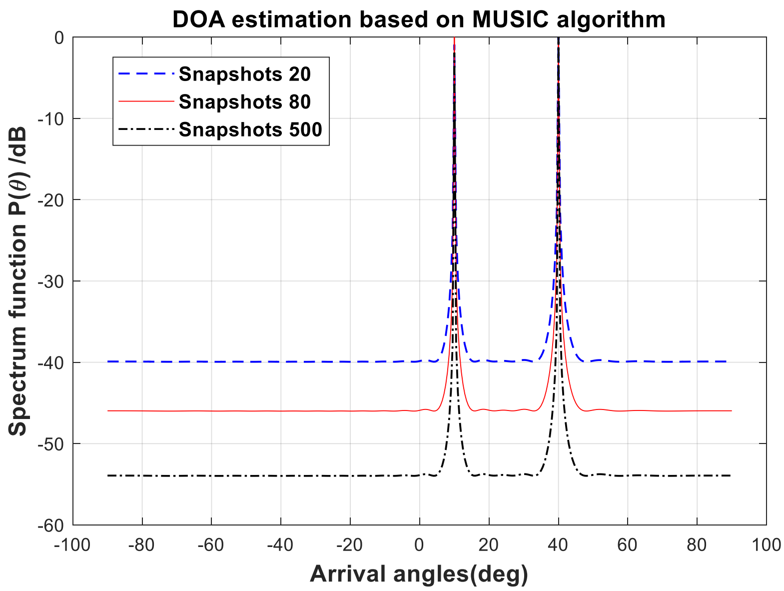


Figure 20. *DOA estimation with different snapshots*

But it is still better to utilize more number of snapshots for better performance as the algorithm counts more samples and it increases the SNR. Hence the more number of samples snapshots more probabilty of accuracy.

4.2.4.4 Inter element spacings

The influence of element space between the adjacent elements at antenna array on DOA estimation has been investigated in MUSIC through this simulation. We kept all the other parameters unchanged in this simulation, and assumed three different element spacings randomly $d = \lambda, d = {}^{\lambda}/_{2}$ and $d = \lambda/4$ respectively for distinguishing the estimation accuracy based on element spacings. It is visible from the resultant Figure 21 that with the increment of array element spacings, the width of the spectrum beam became narrower exponentially and achieved high precision resolution. In comperison , the estimation result for element spacing, $d = {}^{\lambda}/_{4}$ was little bit worse than the $d = {}^{\lambda}/_{2}$. The fact that the gain for $d = {}^{\lambda}/_{2}$ antenna is higher than the $d = {}^{\lambda}/_{4}$. However, there was also a noticeable inconsistency with the estimation result for element space $d = \lambda$. The result of array element space $d = \lambda$ appeared false peak or another unwanted extra peaks because of grating lobe. Increasing element spacing towards $\boldsymbol{\lambda}$ is cause of high directivity with maximum effect of grating lobe,and consequently, result might be deviated from the expectation. So, the larger element spacings result in high signal diectivity.

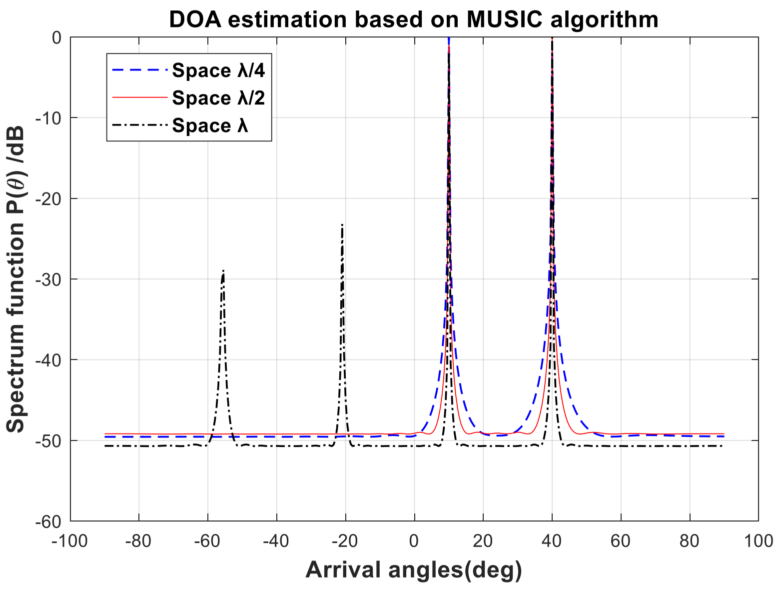


Figure 21. *DOA estimation with different elements spacing*

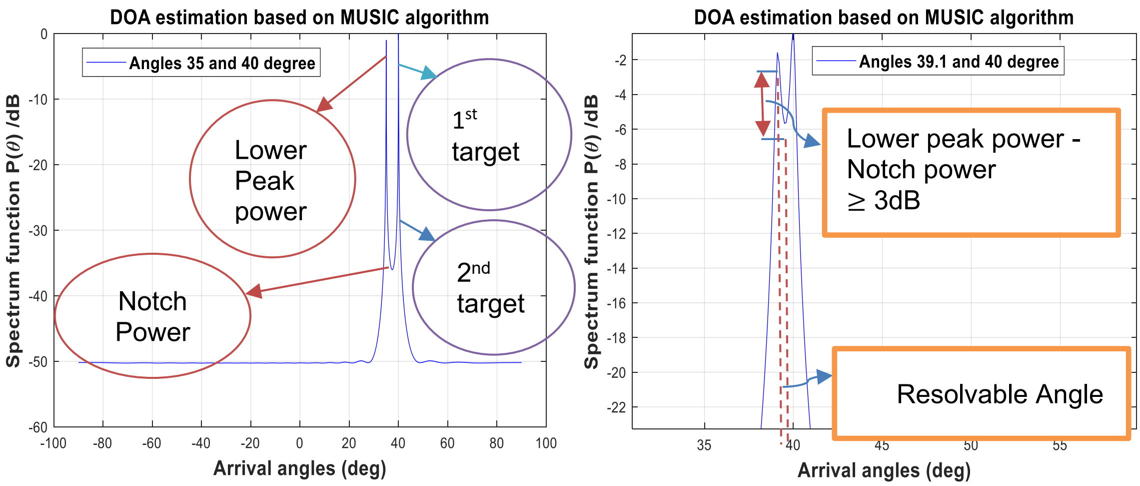
Therefore, it is undoubtly demonestrated by this simulation that the large array element spacings ensure high accuracy DOA estimation but should not be larger than ${}^{\lambda}/_{2}$. Therefore, in case of designing antenna array, inter-element spacing plays an important role, by following proper elements spacing high resolution can be achieved.

4.2.5 Angle resolution

Let us assume, two radar targets arrival angles 35^0 and 40^0 respectively for angle resolution purpose shown in Figure 21(a) . The aim of angle resolution is to obtain super resolution DOA estimation after making the power level of two targets almost the same by gradually step by step increasing the angle of the first target towards the second target whereas, the second target and remaining other conditions are fixed.We continued to increase the power of first target by increasing arrival angle as long as the lower peak power of any of the targets between two and notch power difference become closer to the reference power level ($3\ dB$). We considered mimimum $3dB$ as a reference power level for exprimental purpose. For more clarification, we can simply express the relationship by following equation,

$$|PT_L - P_N| \geq 3dB \tag{17}$$

Where, PT_L is the lower peak power between two targets and P_N is the peak power of notch.



(a) (b)

Figure 22. *Angle resolution (a)initial stage (b) after resolution.*

Once the condition is fulfilled by our simulation, then we calculated the angle difference between two targets which is known as resolvable angle shown in Figure 22(b).

Suppose, at the commencing of angle resolution process, we assumed two targets arrival angles 35^0 and 40^0 respectively. We started step by step increasing the arrival angle of first target towords the second target from 35^0 to 36^0, and then 36^0 to 37^0 and so on. We continued the process as long as our simulation satisfy the aforementioned condition (17). Once we set the first target at 39.1^0, found that our simulation satisfy the condition (17), and then we calculated the resolable angle by following equation,

$$Resolvable\ Angle = |T_{A1} - T_{A2}| = |39.1^0 - 40^0| = 0.90^0 \tag{18}$$

Where, T_{A1} is the arrival angle of first target and T_{A2} is the arrival angle of second target.

Resolvable angle shown in Figure 22(b). However, this above procedure is just an exmple of angle resolution process. For instance, in our experimental study, we assumed two targets arrival angles 35^0 and $40\ ^0$ respectively. For further investigation, the arrival angles can be varied such as 20^0 and 30^0 or $25\ ^0$and 45^0 and so on. And then by applying the aforementioned process, resolvable angle can be find out. We used modulus operator for calculating power difference just for convenience of power calculation.

4.2.6 Effect of parameters on resolvable angles in MUSIC

In this section, we compared the performance of MUSIC algorithm regarding DOA estimation by comparing the resolvable angles with random values of SNR, snapshots, array elements etc step by step, and finally explored out the better performance based on those parameters.

4.2.6.1 Resolvable angles versus SNR

We verified the accuracy performance of DOA estimation based on resolvable angle in MUSIC algorithm by varying random values of SNR. We assumed two incident signals for collecting resolvable angles corresponding to the SNR by increasing the SNR level step by step at high. At the same time, we kept all other conditions unchanged in simulation and established the relationship between resolvable angles and SNR shown in Figure 23. In the high SNR scenario, MUSIC capable of ensuring super resolution. With the declination of SNR level, the performance also degrades sharply. However, here we compared the resolvable angles with SNR level for finding their characteristics in MUSIC algorithm.

From the Figure 23, we found the resolvable angles approximately 1^0, $2^0$and 3^0 for corresponding to the SNR level 70, 60 and $50\ dB$ respectively. On the other hand, for SNR 40 , 30 and $20\ dB$, the resolvable angles were estimated 4.3^0 , 6^0 and 8^0 accordingly.

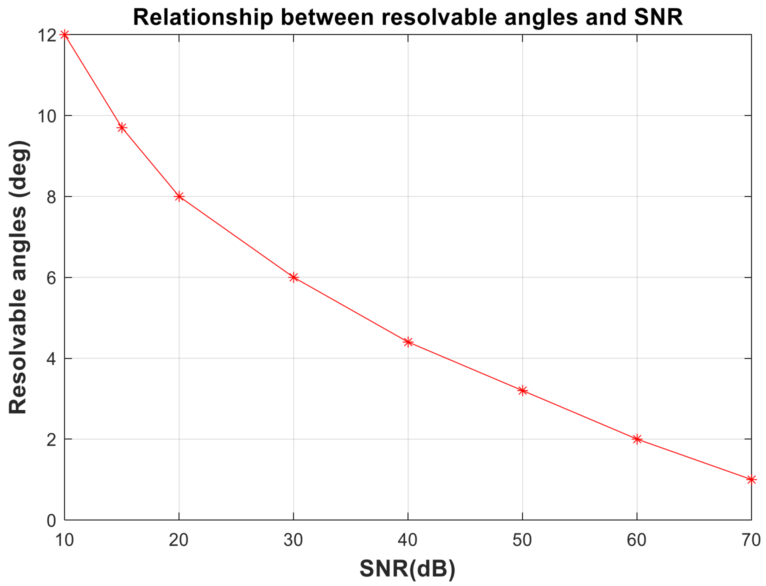


Figure 23. *Resolvable angles vs SNR*

Hence from this statement, it can be concluded that the resolvable angles are in opposition to the SNR value. With the increment of the SNR level, the resolvable angle decreases which means that the estimation gets high accuracy.

4.2.6.2 Resolvable angles versus snapshots

In order to verify the relationship between resolvable angles and the number of sample snapshots in terms of DOA estimation in MUSIC algorithm, we kept all other parameters constant for this simulation except the number of snapshots. We followed the same criterion as in section 4.2.6.1, increased the number of sample snapshots gradually and collected the resolvable angles for each corresponding number of sample snapshots by experimental observation. Afterward plotted them in Figure 24 for understanding the characteristics of number of snapshots on DOA estimation process, how the number of snapshots influence on resolvable angles.

Figure 24 shows the relationship between the resolvable angles and the number of sample snapshots. In X-axis, the number of snapshots and Y-axis resolvable angles have been represented. However, according to the resultant figure, the resolvable angles and number of sample snapshots were seen in opposite trends. We found resolvable angle 4.5^0 for the number of sample snapshots $k = 4$. In contrast, for the number of snapshots $k = 20$, resolvable angle stood approximately 0.95^0.

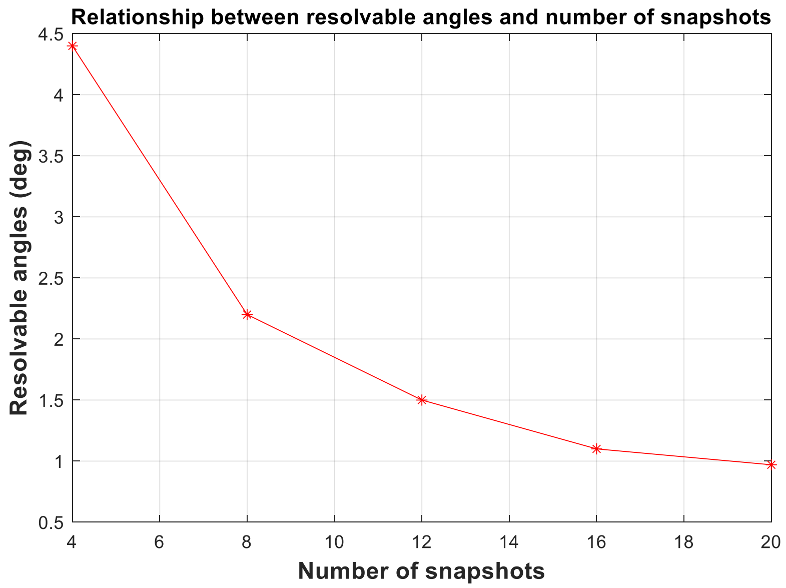


Figure 24. *Resolvable angles vs the number of snapshots*

So, it is simply understandable that with the increment of number of samples snapshots, the resolvable angles sharply declined which means estimation accuracy sharply degrades with the declining of number of sample snapshots. Hence in terms of DOA estimation for resolvable angles in MUSIC with high number of snapshots performs high accuracy, since there is a close relationship between SNR and snapshots. With the increment of number of snapshots noise level become closer zero value, as a result,SNR trend to be high and estimation gets higher accuracy.

4.2.6.3 Resolvable angles versus number of array elements

We compared the accuracy performance of MUSIC algorithm based on the resolvable angle with number of sample snapshots in previous discussion. In this simulation, we showed how the number of array elements influence on DOA estimation process regarding resolvable angle in MUSIC.

Figure 25 shows the close relationship between resolvable angles and number of array elements. In this experiment we used random number of array elements to obtain resolvable angles respect to each number of array element in MUSIC algorithm, whereas other parameters such as the number of sample snapshots, SNR etc. were kept fixed, and finally established a relationship between resolvable angles and the number of array elements by plotting these two data.

Accordance with the resultant output, there was a noticeable influence of number elements on the resolvable angles. However, resolvable angle approximately 3.75^0 was found for the number of array elements $M = 4$. On the other hand, for the number of array elements $M = 24$, resolvable angle was found approximately 0.75^0. Sequentially, for element $M = 8$, $M = 12$ and $M = 16$ resolvable angles were produced approximately 2.20^0, 1.5^0 and 1.10^0 respectively.

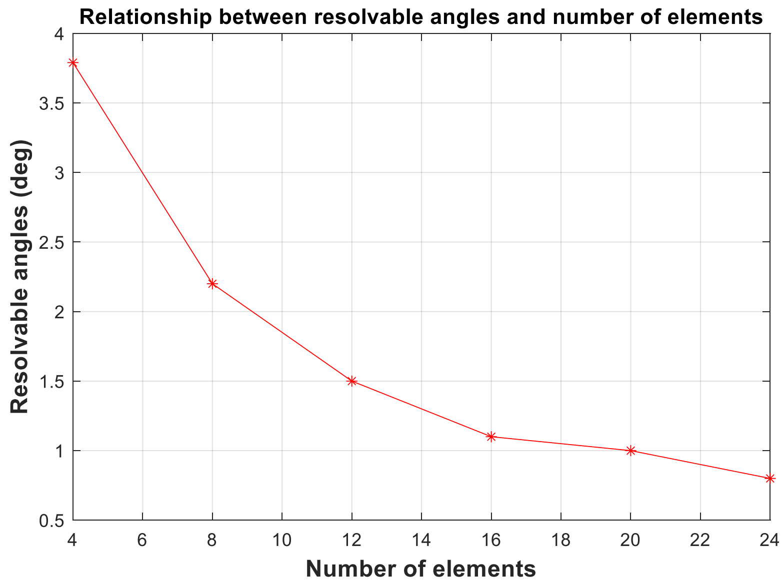


Figure 25. *Resolvable angles vs the number of elements*

Hence with the increment of number elements, resolvable angles decrease which means estimation achieves high accuracy. The fact that the large number of elements in an array will increase the length of antenna aperture result in high gain. To sum up, it can be said that super resolution DOA estimation can be ensured by using high number of elements as well.

4.3 MUSIC in frequency domain

The OFDM is the key technology that has already been adapted in 3G and 4G mobile communication. However, location-based-service (LBS) is the most basic function all along. Regarding TOA estimation, multipath propagation is one the major factor for the degradation of estimation precision. MUSIC algorithm is one of the technique that applied on OFDM system to mitigate the TOA estimation error in multipath propagation [63]. For both the case of DOA and TOA estimation, MUSIC has been proposed as a super-resolution technique. It is a subspace-based algorithm which analyzes by decomposing the covariance matrix of received signal with white Gaussian noise [64]. A detail about TOA estimation for incoming signal at antenna array have been discussed mathmatically in next section.

4.3.1 TOA estimation algorithm

Let us assume, D signal travel through the multipath radio propagation channel and received by an antenna. The summation of attenuated and delayed of impulse response $h(t)$ can be written as mathematically follows [65],

$$h(t) = \sum_{k=1}^{D} \alpha_k \, \delta(t - \tau_k) \tag{19}$$

where, α_k is complex attenuation and τ_k is delay for k^{th} paths.

In order to estimating time delay, equation (19) need to be converted to frequency domain and can be expressed as,

$$\boldsymbol{H}[f_n] = \sum_{k=1}^{D} \alpha_k \, e^{-j2\pi(f_0 + n\Delta f)} \tau_k \tag{20}$$

Where, f_n is carrier frequency,

Δf is subcarrier spacing,

$\boldsymbol{H}[f_n]$ has been estimated by taking the DFT of the received training symbols and dividing, per subcarrier, by known transmitted training symbols.

Steering vector is an important part of MUSIC algorithm, we denoted a time steering vector $\boldsymbol{a}(\tau)$ which represents the channel impulse response of a received signal at time τ,

$$\boldsymbol{a}(\tau) = \begin{bmatrix} 1 \\ exp^{(-j2\pi\tau\Delta f)} \\ . \\ . \\ . \\ . \\ e^{(-J2(N-1)\pi\tau\Delta f)} \end{bmatrix} \tag{21}$$

The subcarrier correlation matrix ($\boldsymbol{R}_{HH}$) can be written as follows,

$$\boldsymbol{R}_{HH} = E\{\boldsymbol{H}[f_n]\boldsymbol{H}^*[f_n]\} \tag{22}$$

The step of MUSIC algorithm for TOA estimation as follows,

Step 1: Collection of data from OFDM symbols, and estimation $\boldsymbol{R}_{HH}$,

Step 2: By applying eigen decomposition, calculate the eigen values and eigen vector from correlation matrix (step 1).

$\boldsymbol{\Lambda} = diag\{\lambda_1, \lambda_2, \lambda_3, \ldots \lambda_N\}$; $\lambda_1 \geq . . . \geq \lambda_N$ are eigen values and $\mathbf{E} = [\boldsymbol{e}_1, \boldsymbol{e}_2, \boldsymbol{e}_3, \ldots \boldsymbol{e}_N]$ are eigen vectors.

Step 3: Estimation of the signal subspace and noise subspace. Take those eigen values and eigen vectors which are equal to the number of signals as signal subspace, rest of the eigen values and vectors are taken as noise subspace.

Step 4: By searching spectrum peaks TOA can be estimated from equation (23),

$$P(\tau) = \frac{1}{[\boldsymbol{a}(\tau) * \boldsymbol{E}_N \boldsymbol{E}_N^* \boldsymbol{a}(\tau)]} \tag{23}$$

$P(\tau)$ generate peaks based on the steering vector and noise subspace vector. $P(\tau)$ generates peaks when noise subspace vector is orthgonal to the steering vector $\boldsymbol{a}(\tau)$ that happens when τ coincides with the arrival time of the incomming signal.

4.3.2 Preliminary result of TOA estimation

In wireless communication, radio signal usually transmitted from transmitter to reciever over wireless medium. TOA basically referers to the absolute time instant between the transmitted time and receiving time at an antenna. In multipath radio signal propagation senerio, there are many possible ways for delayed signal arriving in receiving end and thus signal might reached at the reciver in different time, even though the signal were emanated from the transmitter at the same time. However, there are wide variety of applications of TOA estimation for solving sceince and engineering problems including radar ranging, wireless location findings, delay acquisition for satellite navigation.

TOA estimation is the simplest and well-known method, used for communication ranging, especially in global positioning system (GPS). Figure 26 shows the preliminary result of TOA estimation in MUSIC algorithm applying on OFDM signal. At the initial stage of simulation, we assumed two target signals with arrival delays $20ms$ and $25ms$ respectively for our experimental convenience. However, in practical situation there might have multiple targets rather than two, still this process can be smoothly applied for large number of targets in order for estimating TOA. We deployed the following parameters in Table 5 in MATLAB simulation:

Table 5. *Parameters used for TOA estimation in MUSIC*

Parameters	**Specifications**
Time of arrivals (ms)	20, 25
Number of subcarriers	1024
Subcarrier spacing (kHz)	15
SNR (dB)	30
Number of snapshots	200

Figure 26 shows the TOA estimation output of MUSIC algorithm in frequency domain. MUSIC estimates the time delays of arriving signal at the antenna array by searching the spectrum peaks with high precision.

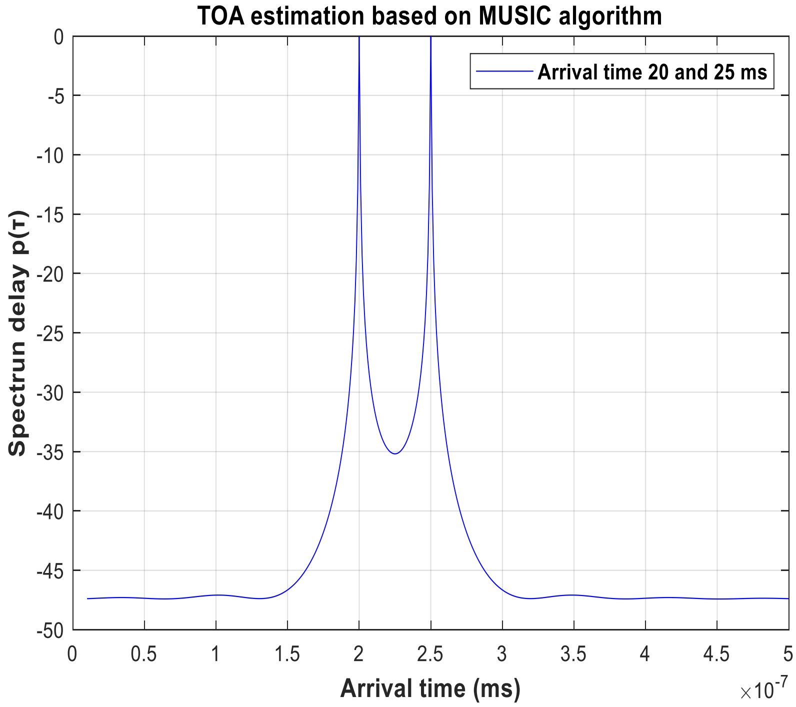


Figure 26. *The preliminary result of TOA estimation in MUSIC*

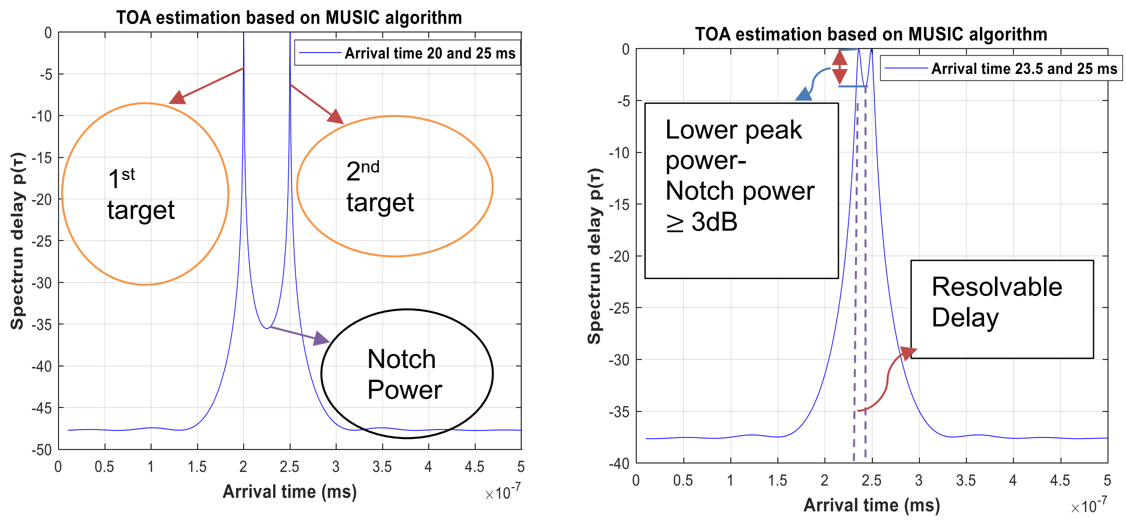
4.3.3 Time delay resolution

Let us assume, the two radar targets with arrival delays $20ms$ and $25ms$ respectively at antenna array shown in Figure 27(a). In order for processing time delay(TD)resolution, the same criterion has been exploited as like in DOA estimation process. Here we assumed minimum $3dB$ as a reference power, which is approximately equivalent to the power difference between the lower peak power of the targets and notch power. Then, we started to resulate TD step by step by increasing the TD of first target towords the second target as long as the lower peak between the targets and notch become $\geq 3dB$. At the same time all other parameters in simulation have been kept fix. For more clarification, we followed the below condition,

$$|TD_L - TD_N| \geq 3dB \tag{24}$$

Where, TD_L is lower peak power between the targets and TD_N is notch power between targets.

Once our simulation satisfied the aforementioned condition after several iterations, then we calculated the TD difference between two targets which is known as resolvable delay. For example, at the initial stage of simulation, we have chosen two targets TDs $20ms$ and $25ms$ respectively for our experimental observation.



(a) (b)

Figure 27. *Time delay resolution (a) initial stage (b) after resolution*

Thereafter we procced TD resoluiton by increasing only the TD of first target towords the second target from $20ms$ to $21ms$, $21ms$ to $22ms$ step by step as long as our simulation satisfy the condition(24). However, we continued this process, and found that once the first target has been set at $23.5ms$, our experimental observation satisfied condition(24), and finally we calculated resolvable delay by following equation,

$$Resolvable\ delay = |TD_1 - TD_2| = |23.5ms - 25ms| = 1.5ms \tag{25}$$

Where, TD_1 is the TD of first target and TD_2 is the TD of second target. The resolvable delay shown in Figure 27(b).

The process of TD resolution which has been expounded here is just an exmple. The incoming TDs can be varied for further scrunitinization and then applying above procedure TD resolution can be found.

4.3.4 Effect of parameters on resolvable delays in MUSIC

We investigated how the performance of MUSIC algorithm changes in TOA estimation with the change of other parameters such as SNR, number of snapshots, number of subcarriers and subcarrier spacings. We have found out better way of high resolution TOA estimation method by next few simulations based on mentioned parameters.

4.3.4.1 Resolvable delays versus SNR

In order to explore out the TOA estimation performance in MUSIC based on the SNR, we adapted different random values of SNR in simulation, meanwhile kept all other parameters same and collected the resolvable delays by changing the values of SNR in ascending order step by step. Afterward, we compared relativity between the resolvable delays and SNR by plotting in X-axis and Y-axis accordingly.

Figure 28 shows the comparative relationship between resolvable delays and SNR.

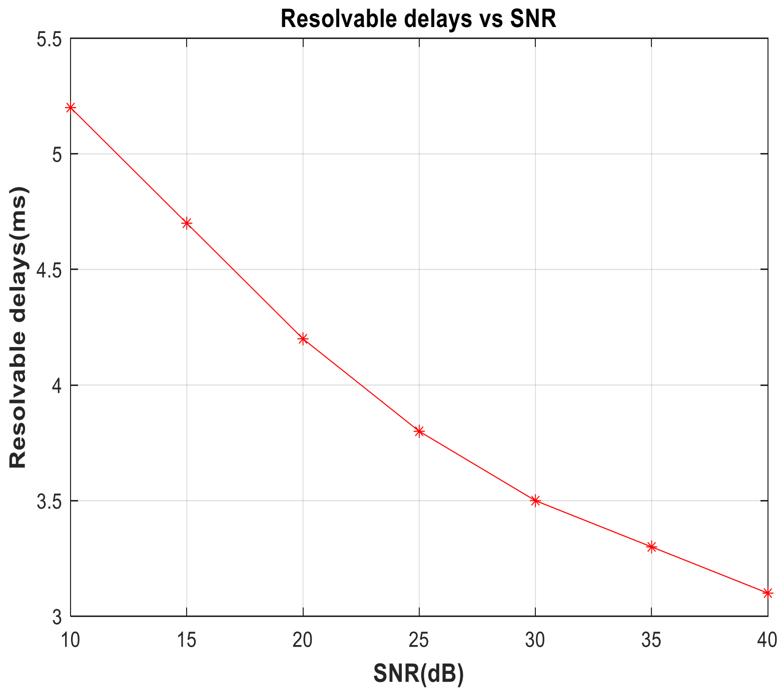


Figure 28. *Resolvable delays vs SNR*

According to the Figure 28, the resolvable delays and SNR was seen in the opposite trend which means if we increase the value of SNR at the same time resolvable delays decreases. However, the curve indicates that in the high SNR scenario, MUSIC algorithm performs high accuracy TOA estimation, contrariwise, the performance becomes poor under low SNR conditions.

4.3.4.2 Resolvable delays versus number of snapshots

We have seen the performance of MUSIC in TOA estimation based on SNR in previous simulation. Here we investigated the performance based on the number of sample snapshots.

For this simulation all other parameters have been kept fixed, for instance, number of subcarriers, subcarrier spacings, number of elements except the number of sample snapshots. We changed the number of sample snapshots step by step from the lower to higher order to collect the corresponding resolvable delays by experimental observation. Finally, established relationship in MATLAB by plotting the number of sample snapshots in X-axis and resolvable delays in Y-axis shown in Figure 29.

According to Figure 29, we can assess relativity between the resolvable delays and the number of snapshots. There was a sharp decline in resolvable delays with the increment of the number of sample snapshots. According to the plot, for the number of sample snapshots $k = 10$, resolvable delay was found exactly $4\ ms$, on the contrary, resolvable delay was produced approximately $1.7\ ms$ for sample snapshots $k = 35$.

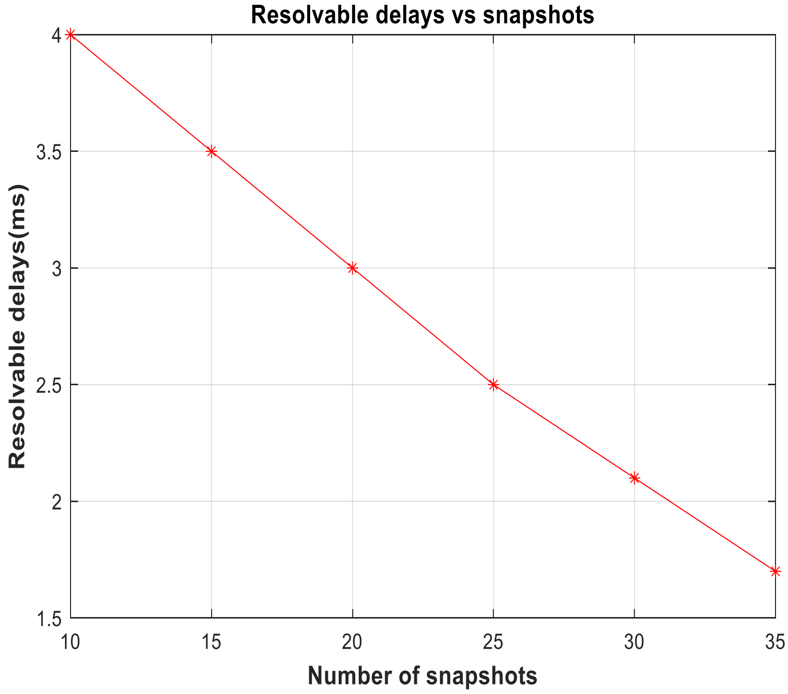


Figure 29. *Resolvable delays vs the number of snapshots*

Hence we can concluded with this statement that the more number of sample snapshots more estimation accuracy. Since the number of sample snapshots and SNR are interrelated to each other. If we exploit more number of sample snapshots in our simulation, the noise level trend to be reduced gradually . Consequently, SNR level goes to high means signal power is higher than the noise power and finally result in high accuracy.

4.3.4.3 Resolvable delays versus number of subcarriers

In OFDM system subcarriers are important part that plays a vital for information transmission in wireless networks. The number of subcarriers should be adapted with other parameters properly by making consistent with the systems for better communication flow. However, we compared the relationship between resolvable delays with the number of subcarriers in MUSIC, in terms of estimating TOA for two radar signals.

From the Figure 30, it is visible that the high number of subcarriers capable of securing minimum resolvable delays between the two targets signals. Our aim is to reduce the TD of the target signals for smooth positioning. Although we worked soley with two target signals for our experimental convenience, this method can be applied for multiple signals.

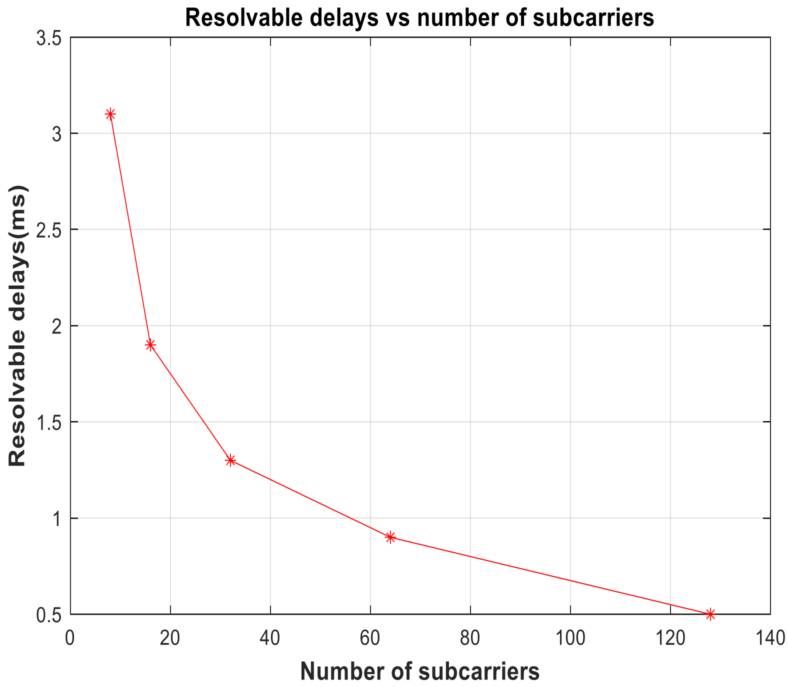


Figure 30. *Resolvable delays vs the number of subcarriers*

The TOA estimation using subspace-based MUSIC supports high number of subcarriers, it also indicates that we should exploit a greater number of subcarriers for working the system perfectly. If too low number of subcarriers are exploited in system, MUSIC might not function well and unable to distinguish TDs of the incoming signal at antenna array due to the low bandwidth. Bandwidth is an important factor that plays a vital role for target localization and ranging operation. There is strong relationship between number of sub-carriers and bandwidth. With the increment of number of subcarriers, bandwidth goes high. On the other hand, high bandwidth is result in decrement of resolvable delays which means TD resolution goes high. Hence, it can be concluded with this statement that high number of subcarriers accelerate the probability of high-resolution estimation.

4.3.4.4 Resolvable delays versus subcarrier spacing

We already discussed in the previous section about the importance of subcarriers for target localization in OFDM communication systems in MUSIC algorithm. For TOA estimation using MUSIC algorithm the effects of subcarriers spacing is also not less negligible. To short out the comparative relationship between the resolvable delays and subcarriers spacings, we plotted subcarriers in X-axis and resolvable delays in Y-axis.

From the Figure 31, it is conceivable that the resolvable delay was found $2.9\,ms$ for subcarrier spacing $15\,kHz$. In contrast, the resolvable delay was sharply declined to approximately $1.1\,ms$ when we adapted the number of subcarriers spacing twice. Similarly, the resolvable delays were moderately becoming smaller according to the increment of subcarrier spacings which indicates that the estimation accuracy was increasing exponentially. The fact that with the increament of number of subcarrier spacings bandwidth also increases proportionaly.

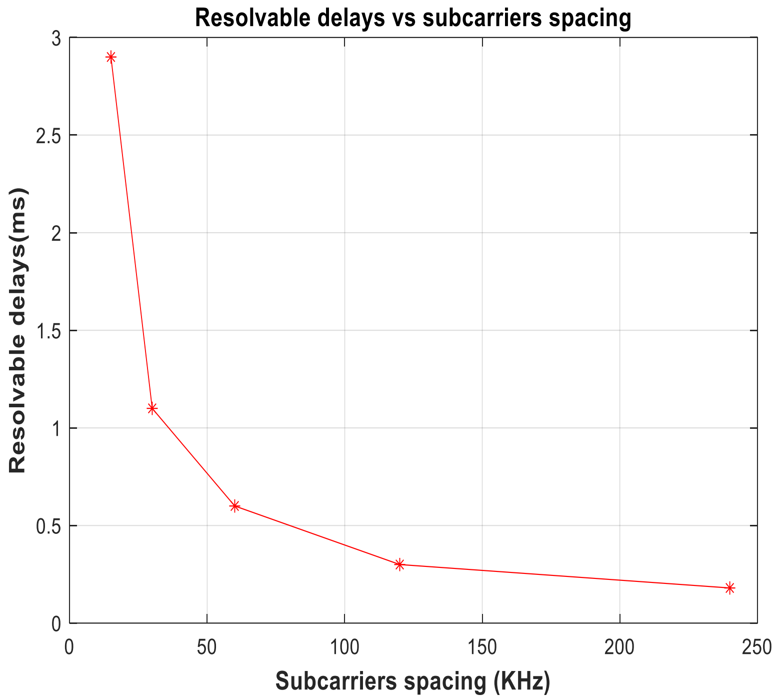


Figure 31. *Resolvable delays vs subcarrier spacing*

In another word, high number of subcarriers spacings enlarge the bandwidth, and large bandwidth is one of the major influential factor for high accuracy estimation.

In a nutshell, we can sum up with the statement that high number of subcarriers spacing usually improve the estimation precision. Hence high degree of estimation accuracy closely depends on the number of subcarriers spacings.

4.4 Challenges in MUSIC

Target localization in the wireless multipath environment is one of the major challenges in radar communication. When signal travels with LOS path is not much affected by power loss. From other hand, signals propagate through NLOS medium result in extra power loss as well as the cause of bias DOA [66]. Unfortunately, NLOS is also cause of biased measurement in TOA estimation also and degrades the overall estimation accuracy [67]. In such a situation, MUSIC algorithm often fails to estimate both DOA and TOA with high accuracy. Furthermore, MUSIC unable to perform perfectly with low SNR as well small number of snapshots. The algorithm provides unbiased estimation for uncorrelated sources even in the presence of a proper antenna model, on the other hand, if the incoming signals are correlated the accuracy of the estimation in MUSIC algorithm goes down even can not estimate DOA. However, in many applications, low SNR, uncorrelated sources as well as low number trials or snapshots might be unrealistic [68].

4.5 Conclusion

In OFDM communication, multiple signals are transmitted using multiple subcarriers within a limited bandwidth. Due to multipath propagation signals fluctuation, ISI is are obvious phenomenon. However, it is easily possible to mitigate these issues by adjusting proper CP length comparing with channel delay spread. However, in such a communication system appropriate estimation method for DOA and TOA need to be incorporated for the targets localization, Especially, for identifying the communication range. The implication of high precision estimation is enormous in global positioning systems.

In order to ensure high-resolution estimation several factors obviously should take in account with great attention. One of the key factors for DOA estimation is antenna array, where the elements are in different spatial areas for receiving the incoming signal from various signal sources in multiple directions. Afterward, by the bless of modern array signal processing direction of source signals can be estimated with high accuracy and swiftly. However, for high-precision DOA and TOA estimation a wide variety of algorithms have been proposed with concrete theoretical and practical applications. In second part of this thesis work is based on MUSIC algorithm with some theoretical and practical MATLAB simulations aiming for high resolution estimation. The main magnetic points and outcomes of the thesis works are summarized as follows,

- In this thesis work, an explicit description about DOA and TOA estimation in OFDM system with proper mathematical model and theoretical aspects have been provided. Thereafter, by deploying MUSIC algorithm for both the DOA and TOA estimations process were implemented in MATLAB simulation for OFDM system, and performances of MUSIC algorithm were assesed through these simulation over different parameters such as number of snapshots, number of elements etc
- Regarding DOA, we analyzed the performance of MUSIC by comparing with different effecting parameters such as SNR, number of array elements, array element spacings, number of snapshots and so on. From the resultant simulation output, we can strongly assert that high SNR, a greater number of elements,

more number of snapshots, and element spacing less than half of wavelength push MUSIC to achieve high precision. Moreover, we compare resolvable angle with those parameters, the carried-out result was the same which means with the increment of number elements, SNR, number of snapshots estimation accuracy gets perfection. But if the elements spacing are larger than half of wavelength cause of poor estimation as well as appears false peaks.

- In respect to TOA estimation, we transfer MUSIC algorithm time domain to frequency domain first, then tried to find out performance by comparing the resolvable delays with various parameters, for example, number of subcarriers, subcarrier spacings, SNR etc. In our findings high number of subcarriers, subcarrier spacing, SNR result in high resolution estimation. However, once the proper estimation done, then it is quite easy to identify the sources or destination of the targets by simple calculation.

4.6 Future recommendations

The proposed methods for both the DOA and TOA estimation in MUSIC have been tested and proven in MATLAB simulation in this thesis work. Both the DOA and TOA estimations are the very huge field in modern signal processing to work on. However, some aspects and inconsistences regarding estimation process have not yet explored and analyzed in our thesis. Those aspects will be incorporated and can be discussed in the future works, they can be summarized as follows:

- Regarding DOA estimation, if the elements spacing become greater than half of wavelength, estimation appeared false peaks goes to targets, a huge research can be organized to improve this estimation issue.
- We noticed in our simulation, at the low SNR, low number of snapshots, a small number of elements MUSIC estimates poor resolution in case of both the DOA and TOA estimation process. Future work can be done for improving estimation accuracy at low SNR, low elements as well as at the small number of snapshots.
- In respect to TOA estimation, MUSIC occupies more subcarriers, subcarrier spacings for obtaining high-resolution TD estimation which means the system is expensive. There are still huge opportunities for further study to optimize the system cost and function effectively at low subcarriers and subcarrier spacings.
- Beside subspace-based MUSIC, there are many algorithms have been already invented, for example, ESPRIT, Root-MUSIC, maximum likelihood (ML) and so

on can be applied in our proposed method for analyzing the estimation performance and making comparison among the findings.

- MUSIC is a perfect choice for DOA estimation in case of independent signal but it often fails to estimate coherent signal too.There is still a massive research opportunity to work on this aspect, how MUSIC can be exploit to estimate DOA for coherent signal.

The mentioned points are the main focusing areas where researchers can contribute for accelerating speed of DOA and TOA estimation process for target localization. Beside these, there are still huge options to work for a massive and sustainable development in the array signal processing field.

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