Impact of Different Modulation Schemes on Millimeter Wave Cellular Systems

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ABSTRACT

This thesis examined the wireless millimeter Wave (mmWave) communication systems which utilize frequency range from 30 GHz to 300 GHz as a candidate of the fifth generation (5G) system. The 5G systems still undergo some problems such as hardware component that improves system efficiency where the following major setbacks are highlighted: very high path loss, shadowing, amplifier non-linearity and phase noise. In this study, using a set of simulations are illustrated in engaging vast bandwidth at mmWave frequencies by Frequency Shift Keying (FSK), the two first mentioned problems, path loss and shadowing, can be relieved while it will not be helpful to tackle amplifier non-linearity and phase noise. In this regard, extensive simulations were conducted and some parameters relating to the influence of the four mentioned problems at mmWave frequencies were defined. The results of this study show an improved performance of non-coherent FSK compared with the other types of modulations like Quadrature Amplitude Modulation (QAM) and Phase Shift Keying (PSK) modulation. Association of this achievement with the relatively slight complexity of non-coherent FSK in terms of the aspect of detection makes it good enough to attain elevated Gbps wireless links at mmWave frequencies. Additionally, as a suitable tool for examination and validation purposes, this suggested simulation can be engaged for assessment of the performance of a broad range of mmWave systems, practically.

Keywords: MmWave, 5G, MIMO, Mobile communication, Path-loss.

ÖZ

Bu tezde, 30 ila 300 GHz frekans aralığını kullanan beşinci nesil (5G) sistem adayı olan kablosuz milimetre-dalga (mmWave) haberleşme sistemlerini incelemiştir. 5G sistemleri, çok yüksek yol kaybı, gölgeleme, amplifikatör nonlineerliği ve faz gürültüsü gibi bazı problemlere maruz kalmaktadır. Bu çalışmada, yapılan benzetim çalışmalarında evre-uyumsuz Frekans Kaymalı Anahtarlama (FSK) kullanılmasının mmWave frekanslarında yol kaybı ve gölgeleme problemine karşı iyi sonuçlar vermesine rağmen, amplifikatör nonlinearliği ve faz gürültüsünde iyileşme sağlanmamıştır. Bu bağlamda, kapsamlı simülasyonlar gerçekleştirilmiş ve söz konusu dört problemin mmWave frekanslarında etkisi ile ilgili bazı parametreler tanımlanmıştır. Bu çalışmanın sonuçları Kuadratür Genlik Modülasyonu (QAM) ve Faz Kaymalı Anahtarlama (PSK) modülasyonu gibi diğer modülasyon tipleri ile karşılaştırıldığında, evre-uyumsuz FSK performansının daha iyi olduğunu gösterilmiştir. Bu başarının, evre-uyumsuz FSK'nın karmaşıklığı, algılama özelliği açısından nispeten az olması mmWave frekanslarında yükseltilmiş Gbps kablosuz bağlantıların elde edilmesini sağlamıştır. Ek olarak, inceleme ve onaylama amaçları için uygun bir araç olan önerilen simülasyon pratikte geniş bir aralıktaki mmWave sistemlerinin performansının değerlendirilmesi için kullanabilir.

Anahtar Kelimeler: MmWave, 5G, MIMO, Mobil iletişim, Yol kaybı.

DEDICATION

I hereby dedicate this thesis to my family, my father who provided me with ample amounts of advice, encouraged self-confidence, self-commitment and self-belief, my mother who taught me responsibility and groomed me to be respectful and appreciative, last but not least my sister who inflicted me with all rounded inspiration and hard work.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

1G	First Generation of Wireless Cellular Network
3G/W	Third Generation/Wideband
σ	Signal Power or Variance of Signal
σ^2_{phn}	Phase Noise Variance
σ^2_{nl}	Hardware Distortion Noise Variance
σ_{shad}	Shadowing-standard Deviation
γ	Path Loss Exponent
ASK	Amplitude shift keying
AMPS	Advance Mobile Phone System
Arg Min	Argument of the Minimum
BER	Bit Error Rate
BS	Base Station
CDMA	Code Division Multiple Access
CMOS	Complementary Metal-oxide Semiconductor
DVBC	Digital Video Broadcasting Cable
DAC	Digital to Analog Convertor
FSK	Frequency Shift Keying
ITU	International Telecommunication Union
IP	Internet Protocol
ISI	Inter-symbol Interference
LTE	Long Term Evolution
LAS	Large Area synchronized
LoS	Line of Sight

LMPS	Local Multipoint Disruption System
LANs	Local Area Networks
MIMO	Multiple Input Multiple Output
MC	Multi Carrier
Mm Wave	Millimeter Wave
MS	Mobile Station
NLoS	None Line of Sight
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RWW	Real World Wireless
RF	Radio Frequency
SMS	Short Message Service
SISO	Single Input Single Output
TACS	Total Access Communication System
UWB	Ultra-Wide Band
WiMAX	World-Wide Interoperability for Microwave Access
WiFi	Wireless Fidelity

Chapter 1

INTRODUCTION

1.1 Background

Wireless communication systems have become an essential part of modern life which plays a dominant role in many socio-economic areas such as catastrophic events transmission, environmental protection, healthcare, business communication, news reporting, entertainment, education changes [1]. This study is focused on comparison of different modulation techniques for mmWave wireless communication systems in terms of efficiency, quality and costs to accomplish sustainable services.

Wireless systems evolve through various means of communication based on their range including satellite, wireless networking, Worldwide Interoperability for Microwave Access (WiMAX), Wireless-Fidelity (Wi-Fi), Bluetooth technology, wireless routers, microwaves, wireless phones etc. whereas the communication via wireless phones is highlighted [2]. Wireless phone communication originated by applying the initial shape of network called 0G that refers to pre-cell phone mobile technology applied by radio telephones which were kept in cars earlier than advent of cell phones at 1992-93 [3]. It was developed in the last generation called 4G with higher quality compared with the former generations, year by year in Figure 1.1. Hence, researchers and engineers have begun trying to offer a higher generation of technology referred to as 5G which will further improve the quality of transmission [4].

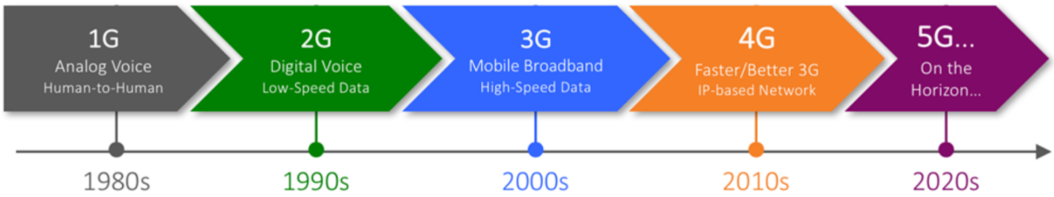


Figure 1.1: Compare of Generations [5]

1.2 Wirelesses Communication

Communication utilizing the electromagnetic signals have been deployed in the 19^{th} century. By the World War II, the mobile telephones became ordinary communication platform. In 1948, entirely automatic cell phones services had commenced operating. Meanwhile, the frequency reuse technology was first debuted by Bell System in a miniscule region in 1969 [6]. Very Large-Scale Integration (VLSI) technology resulted in the low-power application of signal processing algorithms, coding techniques and rapid progress [7]. An enormous interest amongst people in order to have a wireless connection was the main result of VLSI which formed the foundation for more surveys and activities in wireless communication technologies.

1.3 Development of Mobile Communication Systems

The cellphone systems were initially established in Japan and launched in the Sweden, Norway, Denmark and Finland [8]. Zero generation (0G) makes a reference to pre-cellular mobile telephony technology that was prevalent in 1970's such as radiotelephones that were used inside cars before the emergence of cell phones [9]. After that, the generations for cell phone wireless communication starts. Figure 1.2 shows the evolution of mobile technologies.

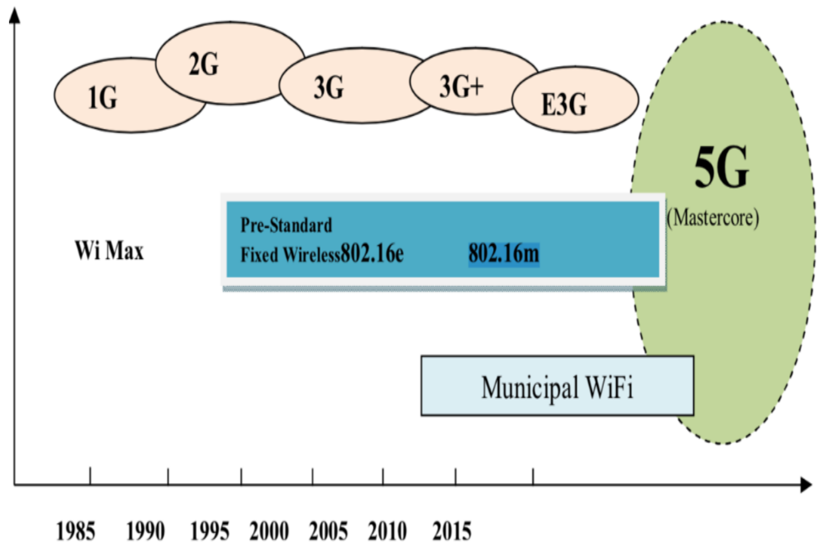


Figure 1.2: Evolution of Mobile Technologies [8]

In the following, a brief history of different mobile communication networks generations will be presented.

1.4 First Generation Mobile Technology (1G)

The wireless mobile communication for the first generation (1G) was solely created and utilized for analog voice transmission. In the 1980s, the first generation (1G) of wireless mobile communication was designed and used just for analog voice signal transmission [8], [3]. The Analog Mobile Phone System (AMPS) was first used in North America then followed by the European countries and other parts of the world as usually recognized as a disparity of Total Access Communication System (TACS) [3]. The modulation system used in these systems was wideband FM, which was inherently analog.

1.5 Second Generation Mobile Technology (2G)

The second generation wireless system (2G) was first introduced in the late 1980s and finally in the late 1990s [8]. Its purpose was mainly for digital voice signal communication with speed up to 64 kbps [3].

The second generation of the mobile communication produce some additional services in comparison with the first generation, namely: short message services, picture message services and multimedia message services. The modulation techniques employed was Gaussian Pulse Shaped, Frequency Shift Keying with minimum possible frequency shift, hence referred to as Gaussian Minimum Shift Keying (GMSK). There was an obvious improvement in quality due to switching from analog to digital modulation techniques [10].

1.6 Third Generation Mobile Technology (3G)

In the early 20^{th} decade the 3^{rd} generation (3G) of mobile services were introduced for the first time. Comparing 1G and 2G technologies with 3G, the data transmission speed increased from 144Kbps (as in EDGE) to 2Mbps as in High Speed Download Packet Access (HSDPA) or High Speed Upload Packet Access (HSUPA), or High Speed Packet Access (HSPA). The modulation technique employed was M-ary Quadrature Amplitude Modulation (M-QAM) with Code Division Multiple Access (CDMA) as the multiple access technique. The third generation/Wideband-Code Division Multiple Access (3G/W-CDMA) air interface standard was presented for the persistence of always-on packet-based wireless service, so the electronics devices, such as computers, could be connected to the internet at any point and utilizing a wireless connection [4].

1.7 Fourth Generation Mobile Technology (4G)

The 4^{th} generation (4G) of the mobile communication system was introduced in 2010. The International Telecommunication Union (ITU) in IMT Advanced defined the criteria for the 4G system. Amended mobile web access, IP telephony, gaming services, high-definition mobile TV, video conferencing, 3D television and cloud compute at very high capacities. The fourth generation of mobile communication is a mobile system based on IP which connects via an integration of radio interfaces with the capability to provision 100 Mbps worth of speed to 1Gbps in high Quality of Service (QoS) as well as better security in comparison with the third one.

1.8 Fifth Generation Mobile Technology (5G)

By the improvement in modulation/demodulation, estimation, detection, coding/encoding approaches, the next generation of mobile technology (5G) would reveal a thousand times improvement in capacity, 10 times improvement in battery efficiency, 5 times improvement in spectral efficiency and reduced latency from 30 ms to 5 ms. The 5G system is expected to continue using Orthogonal Frequency Division Multiplexing (OFDM) as in 4G but stop using Multi Carrier-CDMA (MC-CDMA), Large Area Synchronized-CDMA (LAS-CDMA).

It will also employ Network-Local Multipoint Disruption System (LMDS) and Internet Protocol version 6 (IPv6). Next generation is referred to as Real World Wireless (RWW) or World Wide Wireless Web (WWWW) which it deals better with limitations posed by the previous generations of wireless communications system. Through proposed features and architecture of this system design challenges as well as the deployment of 5G wireless systems could be tackled on. The modulation technique is likely to continue as QAM. The sequence ordering of all mobile generations is provided in Table 1.1 as following.

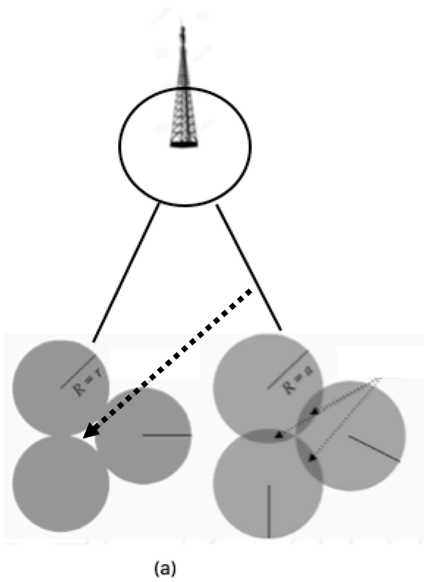
Table 1.1: Evolution of Wireless Technologies [3, 4, 8]

Generation	Definition	Throughput and Speed	Technology	Time period	Features
1G	Analog	14.4 Kbps (peak)	TACS, NMT, and AMPS	1980 - 90	Wireless phones in 1G are used for only voice
2G	Digital Narrow band circuit data	9.6/14.4 Kbps	TDMA, CDMA	1990 - 04	Through multiplexing, multiple users on a single channel are allowed in order to achieve 2G capabilities. Cellular phones on 2G are used for voice and data.
3G	Digital Broadband Packet Data	3.1 Mbps (peak) 500-700 Kbps	CDMA 2000 (1xRTT, EVDO) UMTS, EDGE	2004 - 10	Multimedia service support in 3G and streaming is more popular. Portability and universal access has been made possible in many devices including telephones, pda's and many other devices.
4G	Digital Broadband Packet All IP Very high throughput	100-300 Mbps (peak) 3-5 Mbps 100 Mbps (Wi-Fi)	WiMAX LTE Wi-Fi	Now	The data access demand used by many services is enhanced by an increase in 4G speeds. 4G now fully supports high definition streaming. HD capabilities supported by latest cellphones has surfaced. Roaming cellular networks is no longer a distant memory.
5G	Not now	Probably gigabits	Not now	(most definitely 2020)	At this time there's no 5G technology in use. In the event it becomes available it's going to provision high speed network access to consumers. Every advent of new technology usher in new bandwidth technology and this will also be the case in the 5G technology.

1.9 Cellular Architecture

In 1947, the cellular concept has been introduced by the researchers of Bell laboratories. They intended minor overlapping cells which supported by switching organization to track the moving users through a network. The switching organization is passing the user's call from one site to another one without any disconnection. In the 1970's, the first profitable cellular network has installed in Chicago then it spread all over the world with different utilization such as Wi-Fi, Wi-Max, 3G technologies and 4G LTE at present.

All cellular network was designed to serve users through specific regions. The regions are characterized into practical cells in a desert or vacant area. Figure 1.3 shows the concept of cell architecture.



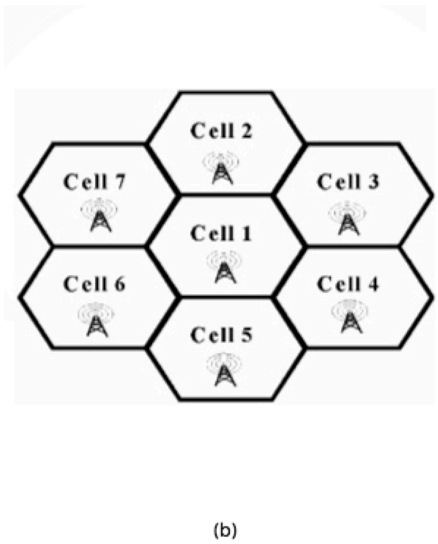


Figure 1.3: Architecture of Cell, (a) Wireless Cell Structure (b) Model of Cell

Figure 1.3, shows the cell structure that is wireless and model of cell. The actual antenna pattern is produced together with the cell structure that is wireless which is circular in terms of the desert and vacant area in the absence of the obstacle, since the pattern of the antenna is omnidirectional. The circular model, however, resembles some problems. Firstly, by placing together the cells does not cover the whole area and therefore there is user Base Station (BS) network disconnection. Secondly, cells are merged together in order to eradicate the prior problem, and that results in an occurrence of interference and overlapping in the system. Engineers therefore, conceptualized a hexagonal shape as a solution to mitigate the problem.

Figure 1.3 (b) shows a hexagonal shape that results from merging cells together causing no overlapping or any non-coverage area. Hexagonal shape, therefore, introduced the concept of cell splitting. For every center of the hexagonal shape, there is BS and all users need to establish a connection through their closest BS. 1G as well as higher generation wireless cellular network up to 4G utilize this architecture but 5G has a different architecture all together due to the type of technologies it utilizes. In practice, the same hexagonal will appear although it bears a different infrastructure.

1.10 Protocol of 60 GHz

This category of wireless protocols operates in a signaling band (range) around 60 Gigahertz (GHz). These frequencies are significantly higher than those used by other wireless protocols, such as LTE (0.7 GHz to 2.6 GHz) or Wi-Fi (2.4 GHz or 5 GHz). This key difference results in 60 GHz systems having some technical advantages compared to other network protocols like Wi-Fi but also some limitations.

By scaling up the number of antennas, the range of the 60GHz radio can be increased to a few hundreds of meters, making the technology attractive for 5G small cell backhaul applications and Fixed Wireless Access (FWA) which will probably become the first 5G use case. With FWA and small cell backhaul, multigigabit per second connections can be brought to the home without the need for fiber in the last kilometer. For FWA, two fixed locations are required to be connected directly. The base station can be put on e.g. a street lamp or a roof top, while the radio link towards the end user is preferably located outdoors for minimal signal loss (e.g. in a box next to the window). Each of the FWA devices is configured to be in line of sight for better signal reception. mmWave FWA can be combined with mmWave backhaul to wirelessly carry the data traffic deeper into the communication network towards the mobile network operator's core network. One option is to use in-line streetlights for deploying the small cells.

Combining 5G FWA and small cell backhaul is ideal in an urban scenario where it would be more expensive or too slow to set up fiber optic backhaul connections. Wireless point-to-point backhaul links can easily be put on street lights or house facades, whereas an alternative fiber optic solution would require more time due to regulation or the need for obtaining approvals for the installation. Or think of a scenario where extra high bandwidth is needed only for a short period of time such as a concert, an important cycling race or a disaster zone.

1.11 Architecture of 5G Cellular Networks

The general study demonstrates 80% and 20% of the time is spent on wireless on and off respectively [11]. Signals need to move through walls for the use of mmWave in 5G systems for in users to link with the BS. Lower signal strength and high Bit Error Rate (BER) are outcomes of high frequency signals with less penetration. Thus, 5G cellular is characterized into two which includes inside and outside setups [12]. Cell design is a dominant element which includes macro, micro and femtocells. BS is another element that responds to high data rate users.

Figure 1.4 shows the 5G network architecture contains all Radio Access Networks (RANs), aggregator, IP network, noncore etc.

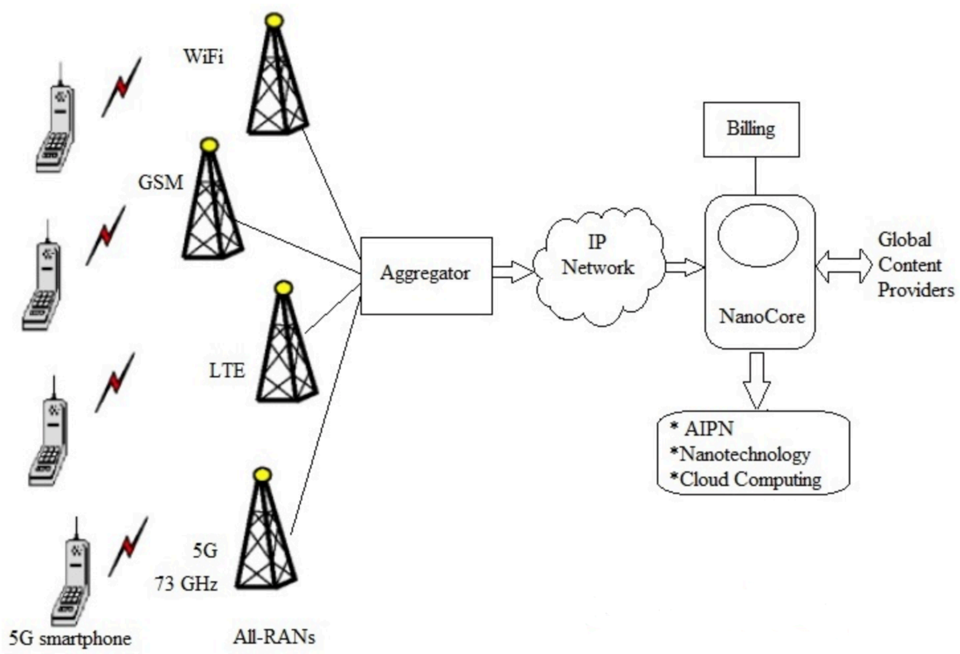


Figure 1.4: Architecture of 5G Cellular [13]

At the top of every building, large antenna arrays could be installed for indoor users so that it communicates with outdoor BS and that could be achieved by the implementation of LOS components. Outside antenna units will be connected to the installed Access Points (AP) via a cable inside the building.

To achieve massive connectivity, large antenna arrays will be furnished for these devices. They will also be equipped with technicalities such as WIFI, mmWave communication, and Visible light communication. All these installations will increase the infrastructure costs, stabilize energy efficiency, cell average throughput, data rate as well as the spectral efficiency.

At every edge of cells, there will be one BS installed for utilization by the outdoor users and it will be connected to the main BS via an optical fiber cable backhaul. Installation costs will increase as the BSs are added at the edge of each cell. This will influence an increase in data rate and coverage area and simultaneously influence an increase in the hand-off as a result of cell breaking into smaller cells. This feature will therefore facilitate massive user connectivity and other similar technologies such as the D2D communications.

5G architecture includes D2D communications, Internet of Things (IoT) and small cell AP. This concludes that 5G architecture is expandable in terms of handling a greater number of connected devices. Without an assistance of a large array of antennas, this architecture is impossible to be achieved. This, therefore gives rise to the briefly explained massive MIMO system.

1.12 Massive Multiple Input Multiple Output Systems

Transmitter and receiver in wireless communication systems with multiple antennas made up the Multiple Input Multiple Output Systems (MIMO). In order to put up more information data computing, the multiple antennas would result in a greater degree of freedom in wireless channels. Therefore, this will lead to an improved performance and as far as efficiency, effectiveness and energy efficiency is concerned.

1.13 Antenna Beamforming

In MIMO system, transmitter sends arrays of streams of data with different direction of beamforming and estimates the channel. This procedure makes it so challenging to detect all corrupted received signals in different angles and moreover to find different behavior for different signals which leads to different values of channel. To make it more sensible, massive MIMO comes with its own challenges as much more antennas are used. As a result of more implemented antenna, more data will be sent simultaneously, and therefore, a lot of interference will be involved. The interference brings a new technology called beamforming to solve the problem.

The beamforming means broadcasting the data not all over the medium but in specific directions and to specific users. This procedure is more efficient and also solves the interference problem between users. 5G can benefited from beamforming considering 5G actually uses these beamformer matrices to estimate the channel.

The working mechanism of beamforming can be explained as follows. If a handset in a cluster of cellular network tries to make a connection to the network a signal travel towards BS in order to make a connection. Through its way, signal collides with surrounding buildings and it gets different shapes and crosses with different users in the area. A massive MIMO BS receives all this data and keeps tracks of timing and directions of their arrival and then it uses signal processing algorithm to triangulate where exactly each signal is coming from, plots the best transmission direction and sends it back to the channel to each phone and the result is a coherent signal stream only transmitted to the desired user. That is why there is different measurement for different users and more complexity in estimation. Next two figures show different scenarios for channel estimation. First one performs with MIMO but without beam-forming and second one has massive MIMO with the use of beamforming.

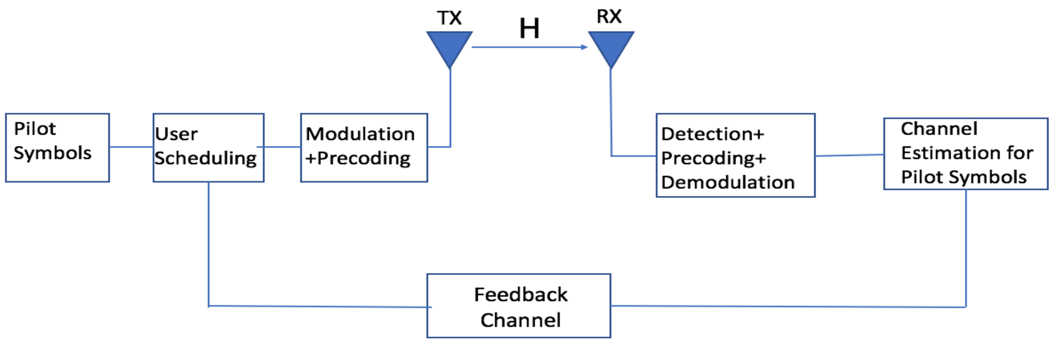


Figure 1.5: Channel estimation at one instance of time without considering beamforming for each user

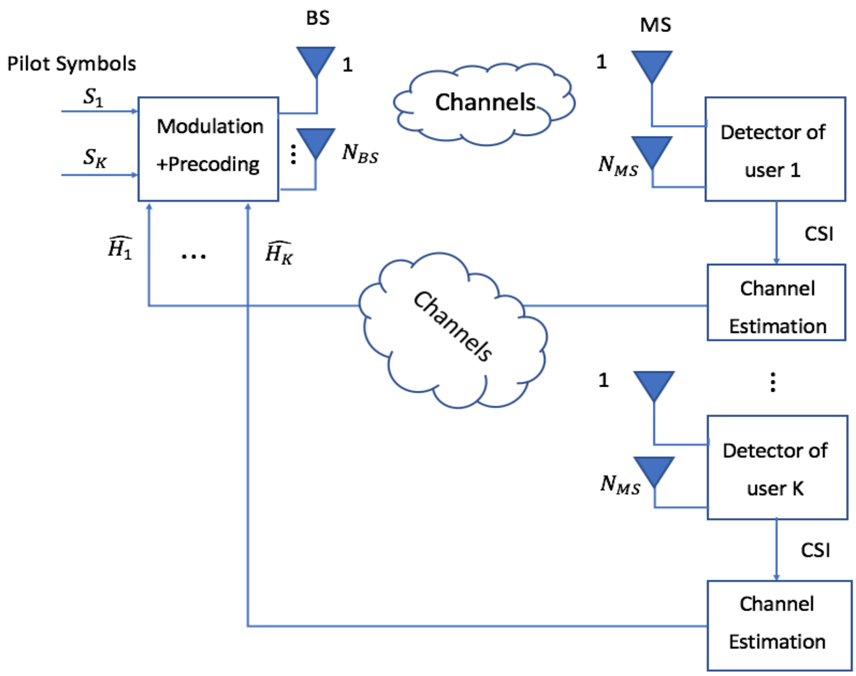


Figure 1.6: Channel estimation for multi-user with massive MIMO and beamforming

1.14 Modulation

Modulation is a process through which audio, video, image or text information is added to an electrical or optical carrier signal to be transmitted over a telecommunication or electronic medium. Modulation enables the transfer of information on an electrical signal to a receiving device that demodulates the signal to extract the blended information.

There are different types of modulation base on modulation techniques used as shown in Figure 1.5.

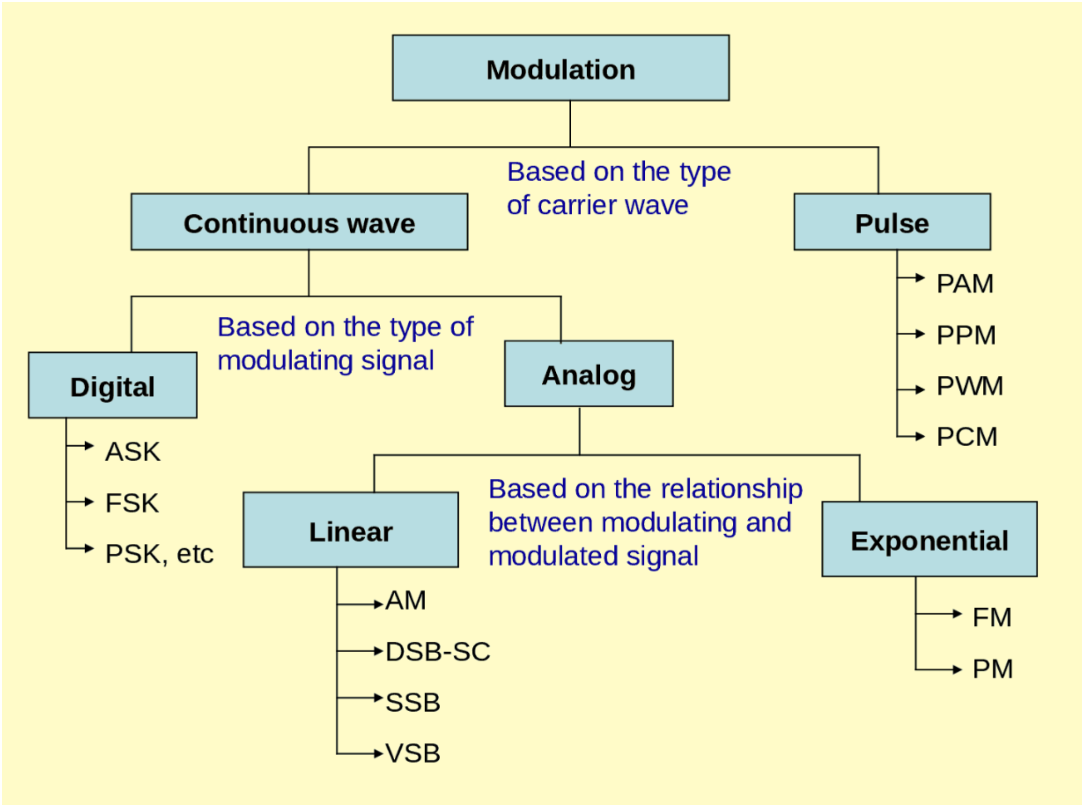


Figure 1.7: Type of Modulation [14]

1.15 Aim of the Thesis

The performance of all communication systems such as bandwidth efficiency, power efficiency, and cost efficiency are concerned can be evaluated. Bandwidth efficiency deals with the modulation's ability schemes to provide larger capacity along with a bandwidth that is limited. While, efficiency of power defines the information transmission ability of systems at the different range of power levels, practically. In the most of valid mobile communication systems, the bandwidth efficiency is prioritized in order to optimize bandwidth utilization according to the demands of the particular system.

In this study, the performance of modulation techniques at higher range of bandwidth by using the mmWave is demonstrated. The results are presented to assess which modulation technique will have a better performance in multipath communication channel at mmWave frequencies.

To support the outcomes of 5G, a setup simulation and a set of criterions that considers effect of path loss, shadowing, amplifier non-linearity, and phase noise at the bandwidth of 60 GHz were formed. Furthermore, the suggested simulation setup may be used for investigating and validating the performance of various mmWave systems in pragmatic configuration. In this regard, the recommended simulation setup could be utilized in the verification and operation of various mmWave systems in pragmatic configuration [15].

1.16 Outline of the Study

The base technology offered for the 5G network is mmWave communication. The capacity for 5G networks is expected to escalate close to one thousand times the by 2020. The spectral efficiency can be increased enough to offer orders of magnitude larger spectrum than the existing cellular systems. By increasing the demands for greater capacity links, mmWave technology will have sufficient capability to this increased demand by usage of modulation schemes with higher efficiency.

The thesis discusses the effect of different modulation schemes such as M-FSK, M-PSK, and M-QAM by using simulation methods on mmWave systems. The simulations include the effect of modulation schemes on mmWave systems that take into account path loss, phase noise, amplifier non-linearity and shadowing at the high frequency (i.e. 60 GHz) band.

In the first chapter, the different generations of the wireless cellular network have been discussed as well as the effect of different modulation scheme on mmWave. This discussion will consist of a summarized description of 1G up to 5G evolution including their history, comparisons and attainments by each and explanation of the way they improved relative to the previous ones. Furthermore, that chapter will briefly discuss the technologies aiding 5G qualify for industry criteria in order to perform better than the available cellular communication network i.e. 4th Generation (4G). In the second chapter, the method of analysis and usage will be discussed. Additionally, details of the system modeling will be presented. In the third chapter, the effect of the simulation setup for mmWave systems will be studied by considering phase noise path loss shadowing and amplifier non-linearity. In the fourth chapter, the results will be presented and discussed in order to reach a conclusion. Finally, in the last chapter, a conclusion of the overall study will be provided as well as limitations and recommendations for future studies.

Chapter 2

IMPACT OF DIFFERENT MODULATION SCHEMES ON MILLIMETER WAVE CELLULAR SYSTEMS

2.1 Introduction

Given the ongoing extensive growth in the demand of mobile data, it goes without saying that the innovation of a fifth generation (5G) to keep up with the demand will certainly expend a substantial spectrum amount in the mmWave bands to expand emerging high communication volumes. Leading research facilities have developed a keen interest in the technology behind the mmWave transmission since it offers greater bandwidth that may facilitate an increased gigabyte per second for every user [16], [17]. Although the mmWave is available to be used in inert environments, for instance the backhaul and indoor hotspots, it still poses a great deal of a problem to use the technology in mobile networks, whereby the encoding/decoding nodes are mobile, complex entailment structures make up the channels, and organization between numerous nodes is tough to maintain. Many digital communication systems, like a mobile cellular communication system, a telephone system or a satellite communication system operate on digital modulation techniques. For the past two decades, studies that extensively investigate digital modulation techniques have been carried out and have produced profound outcomes [18], [19].

Since mmWave hold a frequency range from 30GHz to 300GHz, they are the most relevant alternative for the forthcoming 5G technology. The potentiality of mmWave for commercial usage has only been discovered recently, as the spectrum has previously been expended only in radar applications and military communications for over ten years (with Radio Frequency Integrated Circuits built on compound semiconductor processes and expensive packing techniques). Figure 2.1 below shows the commercial potential usage of the mmWave.

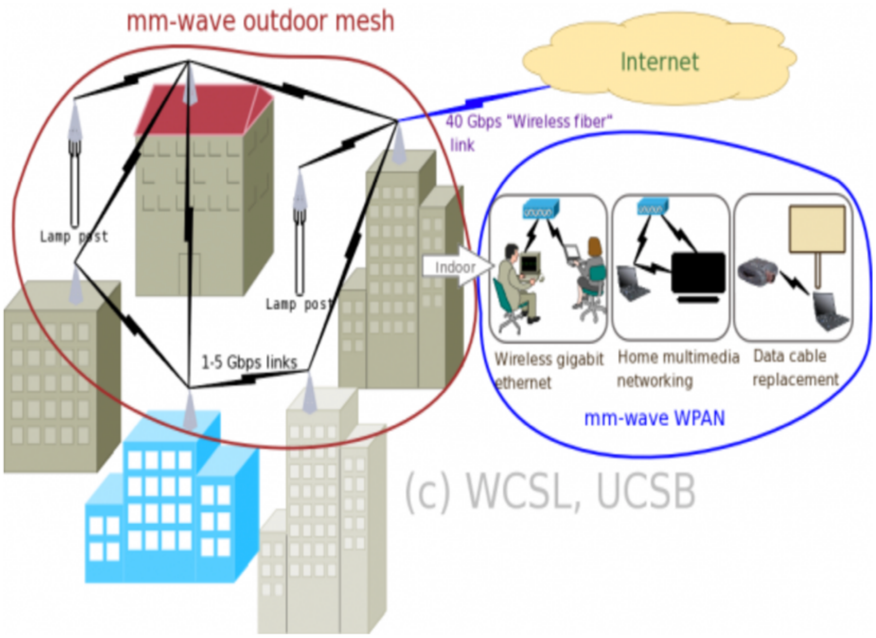


Figure 2.1: Application of mmWave in different field [20]

2.2 Millimeter Wave Wireless

The mmWave wireless technology embodies over one hundred years of progression in contemporary technological communicating techniques. Guglielmo Marconi [21] industrialized and made public the first wireless telegraph communication system in the 1900s.

Ever since, the wireless broadcasting and network technology have expanded tremendously, from radio broadcasting system to wireless networks [21]. The advancement of technology has somewhat become inescapable in our world. Our frequent consumption in wireless local area networks, personal cellular networks and area networks has subjected our modern society into an absorbed usage of wireless networking. Because of the popularity of these technologies, device developers and manufactures sit on a constant urge to discover broader lengths of radio spectrum waves that will facilitate a provision of an advanced product.

2.3 A Preview of MmWave Implementation Challenges

The various setbacks associated with the implementation of mmWave communication pertains to multiple layers of the communication stack. The antennas pose a greater setback at the hardware level of the Physical Layer (PHY). The mmWave chipset merchants may prefer to take advantage of the short carrier wavelength by embedding antenna arrays straight on a chip or in the package to lower costs [21]. Solutions for the single-antenna must surpass setbacks of low on-chip efficiencies whilst in-package antennas must surpass unproductive package intersections.

Antennas in packages or on circuit boards that are less than a centimeter when submerged in high permittivity materials could be utilized by mmWave systems. Protocol adjustments at the signal dispensation level of the PHY and the data link layer to coordinate the beams is required by adaptive or switched beam antenna arrays to provide transmit/receive antenna gain [21].

The main problem would be implementation at these higher frequencies. Like 15dB/km for 60 GHz. So only smaller cells can only be designed, therefore, attenuation could be taken as an advantage as new generation mobile systems are moving towards smaller and denser networks and cells. Furthermore, they are interference-limited. Higher attenuation means less interference.

Also, the available bandwidth will allow higher data rates. The 60 GHz will be for small cell backhaul and the 39 GHz or 28 GHz will be for the 5G mobile access. Frequencies higher than 60 GHz such as 90 GHz and 120 GHz and 240 GHz maybe for WPAN still all this is under research. The biggest challenge would be implementation different mmWave frequency bands on a small terminal, mainly because of the RF and antenna. It will be needing a series of novel approaches to resolve issues with power consumption, packaging, frequency conversion, architecture etc.

2.4 Emerging Applications of MmWave Communications

In mmWave communications, 60 GHZ WPAN and WLAN are the first step in the revolution [21]. 60 GHZ communications have a huge effect on other network technologies and have an additional provision to the first mass-market of the mmWave devices and various communications design occurring in distinctive areas. By employing mmWave communication directions to cross-connect the computers for greater bandwidth, flexibility and low power, data centers could inevitably reduce costs. Lossy and wired cross-connects could be replaced with high-speed wireless cross-connects. Through non-traditional wireless applications, data centers and computational platform renovations will extrapolate the connection to cloud computing. In order to provide higher bandwidths to solve spectrum crunch, cellular systems have to embed mmWave to facilitate a provision for mobile networks, peer-to-peer data transfers, and backhaul in the same bands [16].

The emergence of 60 GHZ and mmWave devices are not at all unique. Research and market developments led to the discovery of backhaul wireless links, intra-vehicular communication, broadband cellular communication, and aerospace communication. Technological breakthroughs in mmWave seek to deliver these applications to broader markets with greater proficiencies.

2.5 Millimeter Wave Solution for 5G Cellular System

The wireless industry has formally rejected requests for its remote advances influenced by advances and revelations in computing and communications that have been carried out by disclosures in computing and communications. The number of the new client utilizing headsets and cases that requires an internet connection to access internet content, despite several industrial research attempts to authorize the most convenient and effective wireless developments. The aforementioned outline will be carried out in the upcoming year for the 4G Long Term Evolution (LTE) in order to mitigate the wireless congestion problems and supply an innovation that will ultimately serve the requests of carriers and customers.

The territory of wireless data rates will consistently produce multi-gigabit data centers. The innovation of financially stable Complementary Metal Oxide Semiconductor (CMOS) will function better in the mmWave frequency groups and will maintain the highest gain possible [22], [23]. Increasing RF channel transfer speeds in mobile radio channels, the limitation of information will be ultimately hiked whilst the stagnancy time is greatly reduced. The bearer frequencies of the mmWave allow the distribution of greater transmission capacity and will facilitate information exchange at a higher rate.

Since mmWave possesses shorter wavelength and higher frequency, it may exhibit spatial handling strategies and polarization, for instance, Massive Multiple Inputs, Multiple Outputs (MIMO) and versatile-beam forming technology are utilized [24].

The BS coinciding with gadget interfaces and backhaul interconnected to base stations has the capacity to utilize larger than the available 4G network patterns in greater populated areas, when considering the gain in data transmission and new platform provided by mmWave. According to a normalized myth in the wireless communication system, the nature of climate and rain weakens the mmWave range, and that, in turn, distorts versatile communication. Since the cell size in urban areas is conditionally in demand within a radius of 200 meters, an alternative of mmWave will mitigate this fallout. The most important methodologies to consider for the future cell are Massive MIMO base station and small cell.

As previously mentioned the mmWave as a band is characterized in the range of 30 GHz – 300 GHz. But the industry viewed mmWave as any recurrence that is greater than 10 GHz. This frequency range can easily contain 200 times more important cells allotment currents that are closely associated to the first Radio Frequency land over 3GHz.

The small mmWave lengths progressively conjoined with low power producing CMOS. RF circuits provide a greater power to component numbers (32 components) that are reduced, and the dimension of the antenna is small. These antennas could be used to induce electrically steerable array that formed up at BS either on a cell phone surface or inside a chip.

This intensive ability has driven an extended exuberance and confidence for the mmWave cell both in the academic community as well as the industry, with a notion that mmWave groups will be rendered prominent in the past 4G and 5G cell frameworks. MmWave signs could be vulnerable against blackouts and uncontrolled quality of channel.

2.6 The MmWave Bandwidth Solution

Even with the advances of 4G LTE, the network is running out of bandwidth. The solution, as seen by 5G wireless network developers, is to add more bandwidth by using frequency spectrum in the mmWave frequency range (Figure 1). With hundreds of megahertz of wireless transmission bandwidth available at center frequencies such as 24, 28, and 38 GHz, 5G wireless networks will be capable of almost zero-latency phone calls and extremely high data speeds.

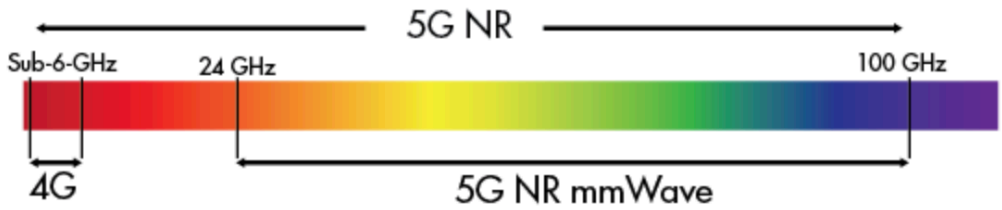


Figure 2.2: The amount of bandwidth available at mmWave frequencies is enormous compared to the amount of frequency spectrum used by 4G and previous wireless network technologies.

2.7 Millimeter Wave Cellular Networks

Mobile communications in these mmWave groups are not new. The mmWave transmission was simulated over a decade ago. Currently, the use of mmWave is predominant in satellite communications and cell backhaul. In the newly unlicensed

60GHz groups, mmWave communications are used for broader yield in Local Area Networks (LANs) and also utilized for Personal Area Networks in the newly unlicensed 60GHz collectives. The connections for these frameworks are catered for small ranges or Point to Point LOS settings.

The detrimental consequences of intense shadowing, irregular network and doppler spreads will result in higher irregular output in mmWave signals. Another issue springs from the exercise of mmWave groups for greater distances and NLOS. The outcome of mmWave signal propagation also stems from larger values of bandwidth that are greater than the present mobile system [16].

2.8 Modulation

The process of changing parameters of the carrier signal, in accordance with the instantaneous values of the modulating signal is called modulation. Practically this process converts signal from source into a signal that is modulated at a higher frequency (the carrier frequency, f_c). The process also involves a carrier wave being translated so that it retains information. The three methods involved in this achievement are using radio communications to transmute a message into the correspondingly high frequency radio channel, using voice-band modems whereby digital data modulate the transmittance of frequencies that is in the voice frequency band and naming the process of obtaining the digital message “Keying”. Therefore, hence the introduction of digital communication terminologies, Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK) and Phase Shift Keying (PSK).

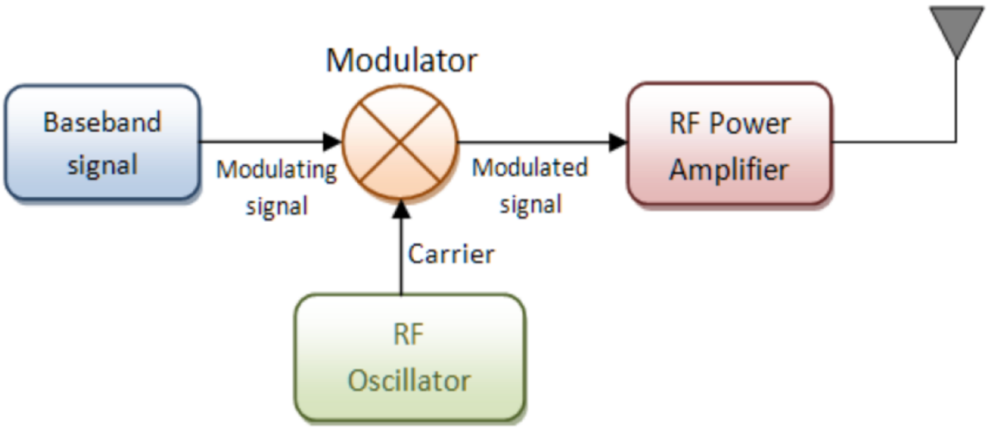


Figure 2.3: Block Diagram of Modulation [25]

2.9 De-Modulation

This is a direct opposite process to modulation. A good example is the broadcast system radio whereby radio transmittance co-equals modulation. A receiver in a radio functions as a demodulator. Another example to give is a modem whereby the action of transmittance and receiving is performed almost simultaneously. A radio antenna demodulates/receives weaker signal whereas a co-axial cable endpoint could also work as a signal input. To boost a signal amplitude an RF amplifier could be used and so the signal will be translated into a demodulator. Since the demodulator receives a signal, the bandwidth signal will be amassed back from the carrier. An audio speaker or video monitor will then be powered up by the base bandwidth signal that also acts as an amplifier so that it corresponds to the computer inputs.

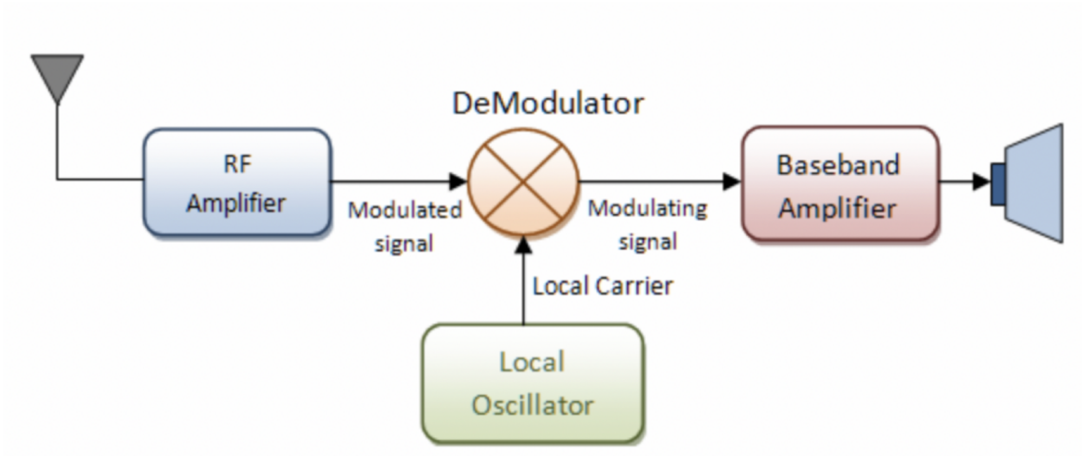


Figure 2.4: Block Diagram of Demodulation [25]

2.10 Types of Modulation

Two types of modulation schemes for bearing signals is digital modulation and analog modulation. The conversion of analog input signal that complies with RF transmission is analog modulation. Baseband signal always acts like an analog in this modulation. Properties making up a carrier signal amplitude and frequency are Amplitude Modulation (AM), Frequency Modulation (FM) and Phase Modulation (PM).

2.11 Amplitude Modulation

An act of changing an immediate amplitude of a carrier signal with an immediate amplitude of a message signal is called Amplitude Modulation. Since both frequency modulation and Phase Modulation are involved in the transportation of a transmitted message that changes in regard to the nature of the message transported, both the modulations co-exist. The AM signal of the complex envelope is represented by

$$g(t) = A_c[1 + m(t)] \quad (2.1)$$

Where, A_c has been included to indicate the power level and $m(t)$ is the modulation signal.

2.12 Frequency Modulation

A technique of analog modulation is Frequency Modulation (FM) and it involves baseband information signal transmission using wireless device. Since it possesses a better noise immunity and its apparent capability to decline signal interference from its effect in capture, frequency modulation could be considered a better alternative compared to amplitude modulation.

2.13 Phase Modulation

PM is the analog modulation technique that involves baseband information signal transmission using wireless device. A process in which a constant amplitude as well as constant frequency sine wave carrier is given to phase shifter output is called phase modulated signal. Since PM produces frequency modulation we call the reversion indirect frequency modulation. The carrier frequency change is therefore in a direct proportionality relationship in relation to the variation effect amount in PM.

2.14 Representation of PM and FM Signals

Special cases of angle-modulated signal include Phase Modulation and Frequency Modulation. The complex envelope in this signaling is given by

$$g(t) = A_c e^{j\theta(t)} \tag{2.2}$$

Where, $\theta(t)$ is a linear function of modulation signal $m(t)$ and $g(t)$ is a non-linear function of modulation signal. Figure 2.4 represent one example for of 3 kinds of analog modulations.

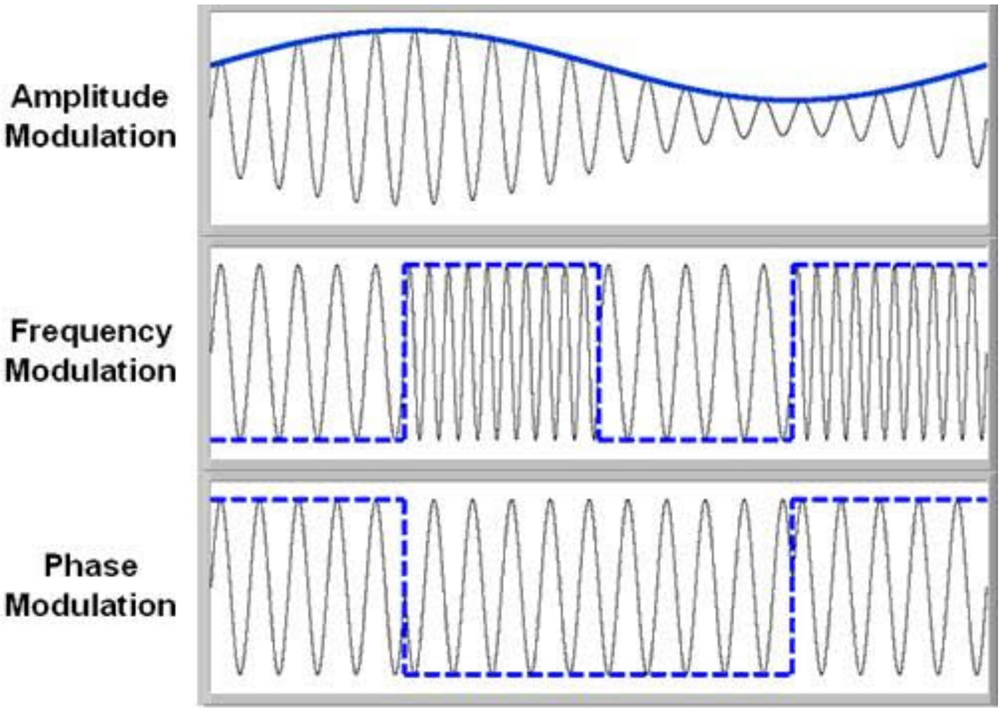


Figure 2.5: Analog Modulation Signals [26]

2.15 Digital Modulation

The process of converting a digital bitstream into an analog signal suitable for RF transmission is digital modulation. The shift to digital modulation provisions in-depth information and digital data services relevancy, security with high data, better communications in better quality and availability in faster systems. Communications developers face the following hindrances: available bandwidth, allowable power and an innate noise level in the system [27].

As the demand for communications services increase, the RF spectrum's need to be shared also increase. Large amounts of information can be easily transferred through digital modulation schemes than analog modulation schemes. The Figure 2.5 shows, digital to analog conversion process.

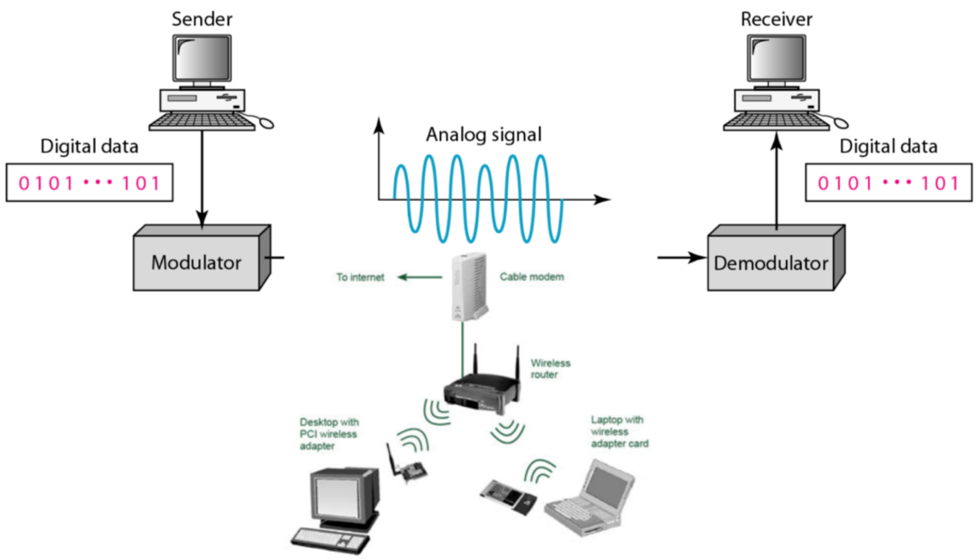


Figure 2.6: Digital to Analog Modulation Process [26]

2.16 Industry Trends

A major shift from analog AM and Frequency/Phase Modulation (FM/PM) to new digital modulation techniques have occurred in the las few years. Examples of this include Quadrature Phase Shift Keying (QPSK), Frequency Shift Keying (FSK) and Quadrature Amplitude Modulation（QAM). A process called multiplexing makes up a new layer in many new systems [27]. The principal types of multiplexing include Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA). Below diagram (Figure 2.6) that adds uniqueness to different signals in order to distinctly separate them.

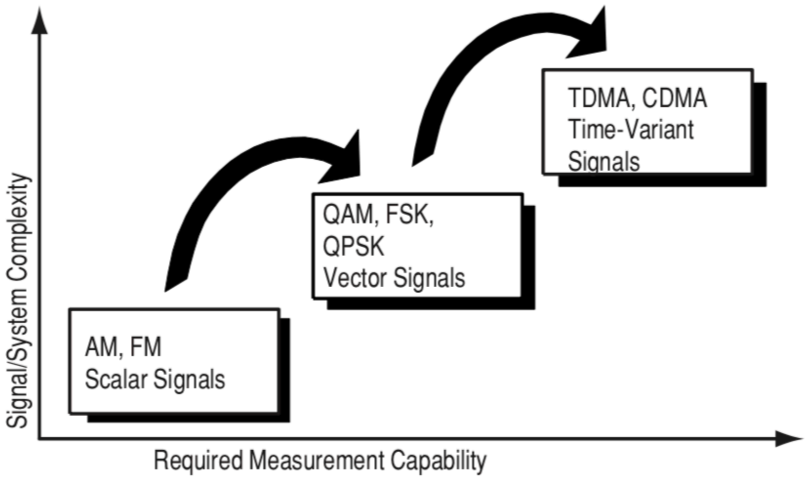
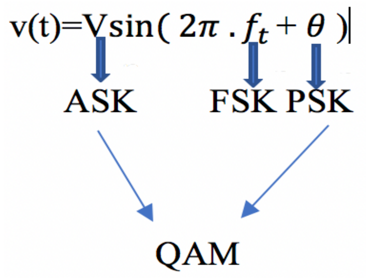


Figure 2.7: Trends in the Industry [27]

Equation (2.3) shows that Provided that the signal information is digital and the carrier amplitude changes according to the information signal proportions, a modulated signal that is digital called Amplitude Shift Keying (ASK) will be created.

Frequency change in proportion to the signal information, Frequency Shift Keying (FSK) will be created, and if the carrier phase changes in proportion to the signal information, Phase Shift Keying (PSK) will be created.

If the phase and amplitude change in proportion to the signal information, Quadrature Amplitude Modulation (QAM) results will be produced as follows ASK, FSK, PSK, and QAM, with all the results being parts of digital modulation.



(2.3)

2.17 Phase Shift Keying

In simple form digital modulation is Bi-Phase Shift Keying (BPSK) or in simplest terms binary. This type of modulation is usually utilized in deep space telemetry. The continuous amplitude carrier peak interchanges in between 0 - 180 degrees. On the I and Q diagram, I represents two distinct values. The possible two locations on the diagram of the state make it permissible to either send 0 or a binary location with the symbol rate being one bit per symbol [27].

QPSK is a phase modulation type that is mostly used and applied highly in wireless local loop, CDMA, mobile phone services, and Digital Video Broadcasting-Satellite (DVB-S) and iridium (a voice/data satellite system). The meaning behind Quadrature application is that the signal moves in additions of 90 degrees starting from 45 to 135, -45, or -135 degrees. An I/Q modulator can be used to implement all the aforementioned points. To receive two bits per second, two I values as well as two Q values could be utilized. Available are four states, hence $2^2 = 4$. Therefore, in conclusion, QPSK is a type of bandwidth with higher efficiency than the BPSK as it offers double the efficiency of its counterpart Figure 2.7 shows one bit and two bits per symbol in BPSK and QPSK Respectively.

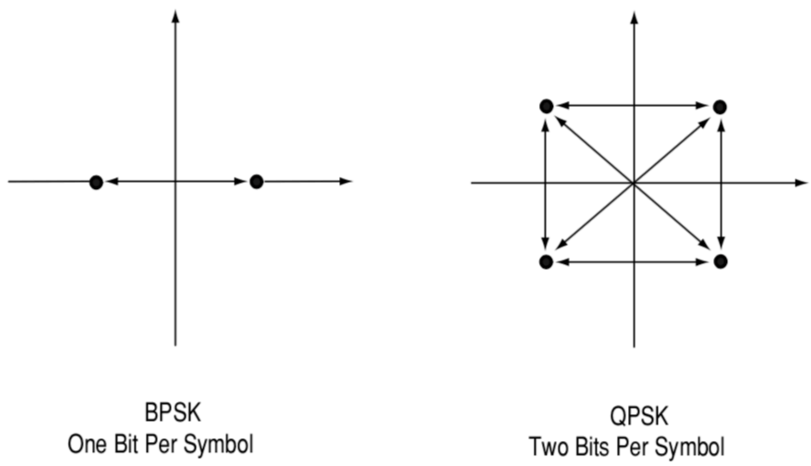


Figure 2.8: Phase shift keying [27]

2.18 Frequency Shift Keying

Frequency and phase modulation intimately relate to each other. A shift in static frequency of +1 Hz could be transcribed as an improving phase with the rate of 360 degrees per second ($2\pi\ rad\ /\ sec$), compared to the phase of the un-moved signal.

FSK is used mainly in paging systems as well as cordless systems. Other types of cordless systems to be mentioned are Digital Enhanced Cordless Telephone (DECT) and Cordless Telephone 2 (CT2).

The carrier frequency in FSK is altered as a setting of the modulating data signal and that is transferred. Amplitude will remain the same. One frequency represents “1” and another frequency in the binary FSK (BFSK OR 2FSK) represents “0”.

2.19 Quadrature Amplitude Modulation

QAM is another member of the digital family modulation. It is mostly used in modems, Digital Video Broadcasting-Cable (DVB-C) and microwave digital radio. The 16-state

Quadrature Amplitude Modulation (16-QAM) consist of four I value and four Q values.

This stems to a totality of 16 possible states for the signal. It can change from one state to the other. Four bits per symbol could be transferred since 16 $=2^4$. This accounts for two bits for I and two bits for Q. One-fourth of the bit rate expresses this rate symbol. This means the format for modulation gives off a more technically orientated and transmission that is efficient [27]. It has higher efficiency more than QPSK, BPSK or 8PSK. It should be noted that QPSK is the same as 4-QAM.

32QAM is another unique set. For this scenario, 6 I values and 6 Q values result in a totality of 36 possible states (6x6=36). Therefore, 4 corner symbol states, which takes the most power to transmit, is taken out. This, therefore results in the reduction of the highest power the transmitter needs to create. Since $2^5 = 32$, there are 5 bits per symbol, the symbol rate equals one-fifth of the bit rate.

Currently, practical limits of 256-QAM is being analyzed, even when work progress to lengthen the limits to 512 or 1024 QAM. 16 I-values and 16 Q-values are used by a 256-QAM system, giving possible states of 256, since $2^8 = 256$, each symbol may represent eight bits. A signal worth 256-QAM that can send 8 bits per symbol has a very linear efficiency.

Nonetheless, the symbols may be too compact and may therefore be subjected to different errors because of distortion as well as noise. Extra power would be necessary to transmit such a signal (to spread out the symbols more effectively) and this will reduce power efficiency when a comparison to simpler schemes is held. Figure 2.8

shows the comparison between the vector diagram for 16-QAM and constellation diagram for 32-QAM.

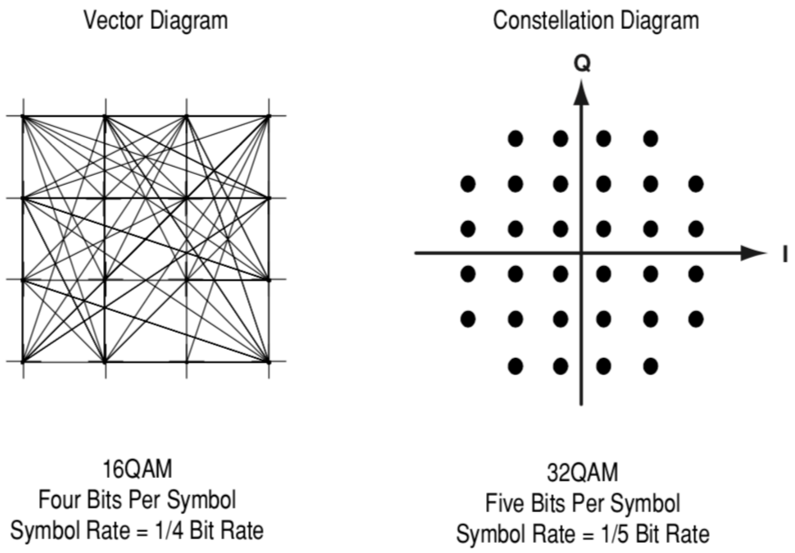


Figure 2.9: Quadrature Amplitude Modulation [27]

2.20 Coherent Wireless Communication

The receiver in the coherent wireless communication has a clear idea of the fading coefficients and the random channel coefficients. The random channel coefficients, h[t] are known at the receiver and the transmitter. Allocating total power budget in a block of length *T* in a way that input power constraint is satisfied and at the same time the highest amount of information is transmitted poses a major problem in coherent communication. The better strategy, intuitively, is allocating more power to the time slots consisting of smaller |h[t]| so that even though the fading is strong, (i.e., $|h[t]|^2 \ll 1$), the input power at that time is large enough (i.e., $|x[t]|^2 \gg 1$) such that the received power, $|h[t]x[t]|^2$, would be suffice to perform the decoding reliably.

2.21 Non-Coherent Wireless Communication

The actual manifestation of the channel coefficient is not explicit to the receiver as well as the transmitter for non-coherent wireless communications. By only using the statistics of the coefficients, the encoding and decoding should be performed.

2.22 Bit Error Rate and Signal to Noise Ratio

Parameters that closely correlate with radio links and radio systems of communication include signal to noise ratios as well as $\frac{E_b}{N_o}$ figures. The Bit Error Rate, BER, could in other words, be explained in reference of the probability of error or POE. Three more variables are utilized in order to determine this concept. These consists of the error function, erf, the noise power spectral density (which is the noise power in a 1 Hz bandwidth) N_o [28] , and the energy in one bit E_b.

It is possible to define the BER in terms of a Probability of Error (POE).

$$\text{POE}=\frac{1}{2}\,(1 - \text{erf})\sqrt{\frac{E_b}{N_o}} \tag{2.4}$$

For the error function, it should be noted that each different type of modulation possesses its own value. This is mainly because each unique modulation reacts in a unique way to noise.

This is because each type of modulation reacts differently to noise. Higher order modulation schemes, in particular (e.g. 64QAM, etc.), may carry higher data rates and are not impulsive and productive when they're in the presence of noise. When lower order modulation formats are in the presence of noise (e.g. BPSK, QPSK, etc.) may provision lower rates of data but they're impulsive and productive.

The energy per bit could be calculated by dividing the carrier power by the bit rate and is a measure of energy with the dimensions of Joules. N_o is a power per Hertz and therefore this has the dimensions of power (joules per second) divided by second. Looking at the dimensions of the ratio $\frac{E_b}{N_o}$ all the dimensions cancel out to give a dimensionless ratio. It is important to note that POE is proportional to $\frac{E_b}{N_o}$ and is a form of signal to noise ratio.

2.23 Lower Order Modulation

At the expense of data throughput, lower modulation order schemes could be used. All the available factors, the BER, to achieve satisfactorily should all be balanced out. Some trade-offs are required in the event it's impossible to achieve all the requirements. In the BER of what is usually required, trade-off could be carried out in terms of the levels of error correction that is initiated into the transmission of data. More redundant data has to be transmitted with greater levels of correction error, and this could help in improving the overall BER by blocking the effects of bit errors that result.

The BER parameter is often quoted for many communications systems and it is a key parameter used in determining what link parameters should be used, everything from power to modulation type.

2.24 System Model

If a transmitting channel that has a narrowband $h \in \mathbb{C}$ with a symbol of information $x_n \in \mathbb{C}$ representing noise that is additive $v_n \in \mathbb{C}$, will therefore result, where *n* represents the symbol of index. This means that physical RF transmitters and receivers have malfunctioning impairments malfunctioning including IQ imbalance, phase noise and amplifier non-linearity. For these impairments, the collective swaying can be depicted by a more general channel model [29], [30], whereby the equation representing the signal received is

$$y_n = e^{j\varphi_n} \, h \, (x_n + \eta) + v_n, \tag{2.5}$$

Where, φ_n correlates to the n^{th} example of phase noise and η is used to simplify the phase noise appearing from impairments of transceiver, including in-phase and quadrature-phase (IQ) imbalance [31] as well as amplifier non-linearity. Additive noise v_n is presumed to be a Gaussian process and white with $v_n \sim CN\,(0,\ N_o),\ \forall n,$ and N_o represents a bandwidth with noise for every power in a unit. Based on [32], [33], Brownian motion or Wiener process could be used to model the phase noise process and this is represented by

$$\varphi_n = \varphi_n - 1 + \Delta_n \tag{2.6}$$

Where, the innovation of phase noise Δ_n is presumed to be a white real process of Gaussian with $\Delta_n \sim N(0, \sigma_{phn}^2)$ and σ_{phn}^2 is variance of the phase noise process of innovation [30]. The noise of distortion resulting from impairments hardware η, in (2.5), could be carved out to be a Gaussian process that is complex with $\eta \sim CN(0, \sigma_{nl}^2 P)$, where $P = \mathbb{E}_{x_n}\{|x_n|^2\}$ is the information symbols of average power and σ_{nl}^2 is the variance of the distortion noise hardware [31]. In (2.5), the channel that is wireless represented by h is modeled by [34].

$$h = \sqrt{\frac{\mathcal{K}(f_c)}{\psi}\left(\frac{d_o}{d}\right)^{\gamma}} \left(\sqrt{\frac{k_R}{1+k_R}} h_{LOS} + \sqrt{\frac{1}{1+k_R}} h_{NLOS}\right) \tag{2.7}$$

Where, $\mathcal{K}(f_c) \triangleq \left(\frac{\lambda}{4\pi d_o}\right)^2$, $\lambda = \frac{c}{f}$ the wavelength for the signal of the carrier, speed of light is represented by c, f_c represents carrier frequency, d_o is the distance of reference, ψ represents a variable that is random with a distributed log-normal that reflects the effects of shadowing so that μ_{shad} and σ_{shad} represent the mean as well as the standard deviation of correlating random variable with a distribution of $10\log_{10}\psi$, d represents the total distance from transmitter to receiver, γ is represents the exponent of path loss, $h_{LOS} \triangleq e^{\frac{j2\pi a \sin\theta}{\lambda}}$ represents the line-of-sight channel component, $a = \frac{\lambda}{2}$ represents the spacing antenna, θ is the arrival angle,

$h_{LOS} \sim CN\,(0, 1)$, is the distribution of the normal complex of the component of sight channel, and the contributes h_{LOS} and h_{NLOS} to the totality channel depicted by the Rician factork_R .

In (2.7), the factors (f_c) , γ, and d correlates to the large scale fading whilst factor $\left(\sqrt{\frac{k_R}{1+k_R}}h_{LOS} + \sqrt{\frac{1}{1+k_R}}h_{NLOS}\right)$ correlates to the wireless channel in small scale fading. It should be noted that the model in (2.7) looks similar to the one utilized for system of microwave communication, although high levels of phase noise is experienced by mmWave, amplifier non-linearity, path loss, and shadowing [34]. The practical value range for mmWave systems are listed in Table 2.1.

Using a non-coherent FSK modulation whereby the information symbols on the same phase are not obligated to be similar and the signals do not move in a continuous path at bit transitions. For the concept of orthogonality, the frequency modulation in the two sets should be the multiple integers of $\frac{1}{2T_s}$ and their distance must be multiple integers of $\frac{1}{T_s}$ where T_s is defined as the period of symbol.

We're proposing the usage of non-coherent FSK modulation whereby the two phases of distinguished information of modulation set symbols should not entirely be similar, also the bit transitions have no continuous signal [35]. For orthogonality, the two sets of modulation frequencies must be multiples of integers of two of $\frac{1}{2T_s}$ and they should be separated by an integer multiple of $\frac{1}{T_s}$ where T_s defines the symbol period.

Though requirement for the bandwidth for non-coherent FSK is bigger when it compared to other modulation techniques, like PSK and QAM, however, we are aiming for mmWave communication whereby the bandwidth is abundant and is of lesser concern. The non-coherent FSK main advantage is its complexity in detecting and is shown through the simulations in the sections to follow, it could use up the large amount of bandwidth at mmWave frequencies to eradicate a path loss exponent and reflect off in this band, while simultaneously turning to become deliberate to amplifier non-linearity and phase noise.

Due to the scarcity of bandwidth in the microwave band, non-coherent FSK has been mainly pushed to the sidelines in to- day's cellular networks. The M-ary non-coherent FSK utilizes a larger bandwidth as the size of the constellation. On the other hand, it can be easily calculated that a system using 4-ary non-coherent FSK and achieving the same data rate as above needs 4 times as much bandwidth or 4 GHz to be exact. However, unlike QAM or phase shift keying (PSK), whereas the order of modulation set, M, increases the bit error rate (BER) of the system also increases, the BER of M-ary non-coherent FSK decreases with an increasing M [31].

Table 2.1: Value Ranges Used In Different Parameters For Simulation [34], [29], [36].

Simulation Parameters	values
phase noise variance σ_{phn}^2	$\{10^{-4}, 10^{-3}, 10^{-2}, 10^{-1}\}$
hardware distortion noise variance σ_{nl}^2	{0.1,0.2,0.3}
shadowing-standard deviation σ_{shad}	{0, 3, …,12} dB
Path loss exponent γ	{3,3.5, …,5}

Chapter 3

SIMULATION SETUP FOR MMWAVE SYSTEMS

3.1 Introduction

A simulation setup for mmWave systems that consider for path loss, amplifier non-linearity, and phase noise will be presented in this section. In order to authenticate and examine the functionality of various mmWave systems in a pragmatic configuration, we can consider applying the simulation described below. Table 2.1 in chapter 2 illustrates the range of values together with references which we consider for the simulation parameters in our research. It should be noted that the expanded variety in values to assess the hardware impairment as well as the channel distortion in order to gauge performance in non-coherent FSK is considered.

3.2 Phase Noise

3.3.1 Definition of Phase Noise

This is the most important parameter in many oscillators and it shall be discussed extensively regarding its origin, its effects and how it could be reduced in an oscillator design.

Phase noise originates from small oscillations in the configuration of an electronic signal. Because Phase noise is the fundamental limitation in the performance of systems that limit dynamic range, we specify and measure it. Radar and communications show loss of sensitivity in imaging because of absence of definition in digital systems as higher Bit Error Rate. This discussion will primarily focus on phase noise in frequency domain and in its quantified jitter in the time domain [37].

3.3.2 Phase Noise Model

At high frequencies in mmWave communication, the effect of phase noise is more productive [38]. In the Si CMOS technology, it was determined that the phase noise variance is $\sigma_{phn}^2 = 10^{-3}\ rad^2$ at f_C = 60 GHz and 1 MHz bandwidth in Si CMOS system [36], by increasing the carrier frequency through an increase in the phase noise variance. To simulate, we investigate the results of the variation of phase noise variances $\sigma_{phn}^2 = \{10^{-4}, 10^{-3}, 10^{-2}, 10^{-1}\}$ on the system performance

3.3 Amplifier Non-linearity

3.3.1 Definition of Amplifier Non-linearity

Non-linearity is the behavior of circuit, specifically an amplifier in which the signal strength output is similar in proportion to the signal strength. The output-to-input (gain) amplitude ratio in a non-linear device is depends on the strength of the signal input.

An amplifier that shows non-linearity, the output-versus-input signal amplitude graph appear as curved lines over part or all the input amplitude range. The two examples depicted below (Figure 3.1) show the amplifier shown by the number 1 curve increases as the input signal strength increases and the amplifier shown by the number 2 curve decreases as the input signal strength shown by the amplifier decreases.

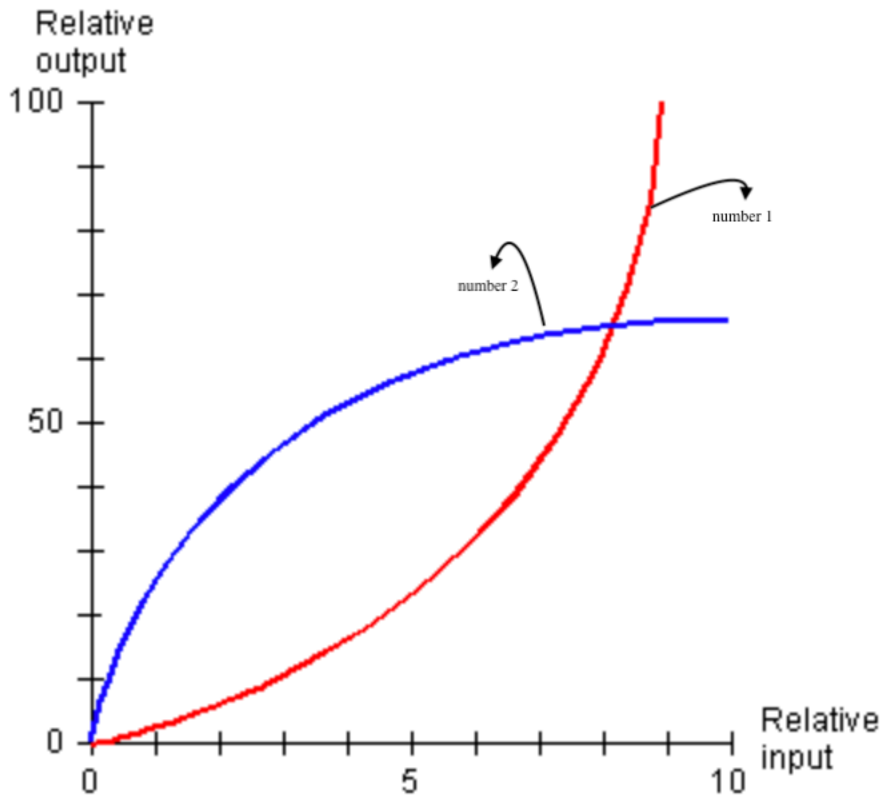


Figure 3.1: Example of non-linearity [39].

Devices and systems as well as FM wireless transmitters that use digital modulation could facilitate non-linearity. Signals could either be full-on or full-off. Since the amplitude waveforms are not analog, analog waveforms cannot take place. Linearity is however important in analog systems and devices. Distortion happens in applications such as AM and wireless transmission as well as hi-fi audios.

3.3.2 Amplifier Non-linearity Model

An example of impairment hardware effect could be the amplifier nonlinearity which is critical at high frequencies in mmWave communication [37]. In particular, hardware distortion noise variance of $\sigma_{nl}^2 = 0.15$ could mean the most intense microwave communication.

Currently there hasn't been any discovery of non-linearity model similar to the one resembling mmWave systems. That is why the distortion noise range effect noise variances of $\sigma_{nl}^2 = \{0.1, 0.2, 0.3\}$ is investigated on different performances of modulation schemes. Figure 3.2 shows the block diagram of non-linearity amplifier at the receiver.

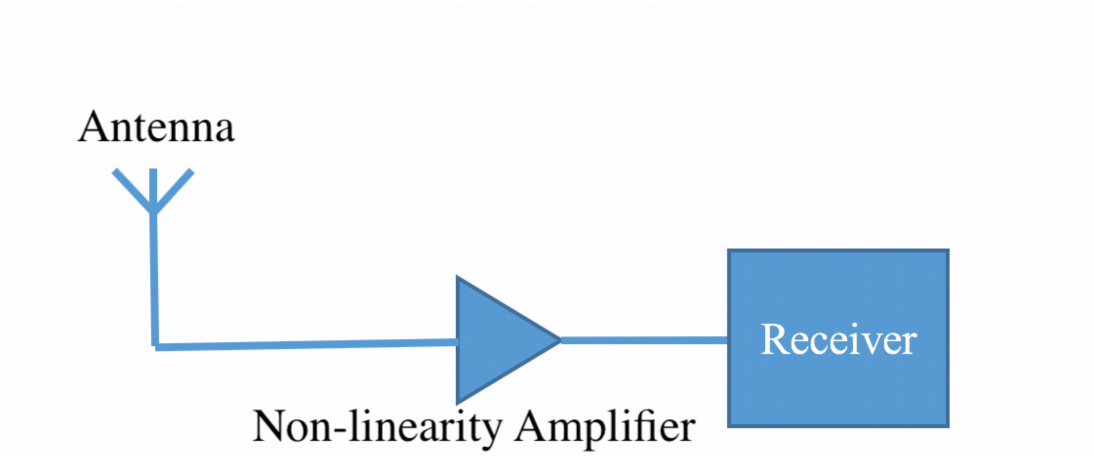


Figure 3.2: Block Diagram of Non-linearity Amplifier

3.4 Shadowing

3.4.1 Definition of Shadowing

The deviation of the power of the received electromagnetic signal from an average value represents the definition of wireless communications. Obstacles affecting the wave propagation cause this phenomenon. This may differ with geographical position or radio frequency. This is usually modelled as a random and unified process.

3.4.2 Shadowing Model

The shadowing-standard deviation of $\sigma_{shad} = 9.13\ dB$ at 28 GHz concludes the experiments as well as the empirical results that are conducted for mmWave in communication systems of communication. Since we conduct the study of the effect of channel distortions over an expanded range of mmWave frequencies from 40 to 120

GHz, in particular of over 60 GHz band, we take into account the values of $\sigma_{shad} = \{0,3, \dots ,12\}\ dB$ to assess the effects of shadowing on different modulation schemes.

3.5 Path Loss

3.5.1 Definition of Path Loss

The received power of the propagation of electromagnetic signals deprived through space is path loss. Factors contributing to path loss include free space path loss, diffraction, refraction, cable loss, absorption as well as coupling. Other factors dependent on Path loss include type of propagation, environment, height and location of antennas as well as the distance between receiver and transmitter. The antenna that transmits the signal could take unique multipath in order to connect to one side that receives the signal, which ultimately creates an outcome in which a decrease in the signal or an increase in the signal with a receipted level is dependent either in the multipath waves that have either a destructive interference or constructive interference [40]. Figure 3.2 shows the relationship between transmitter and receiver on path loss.

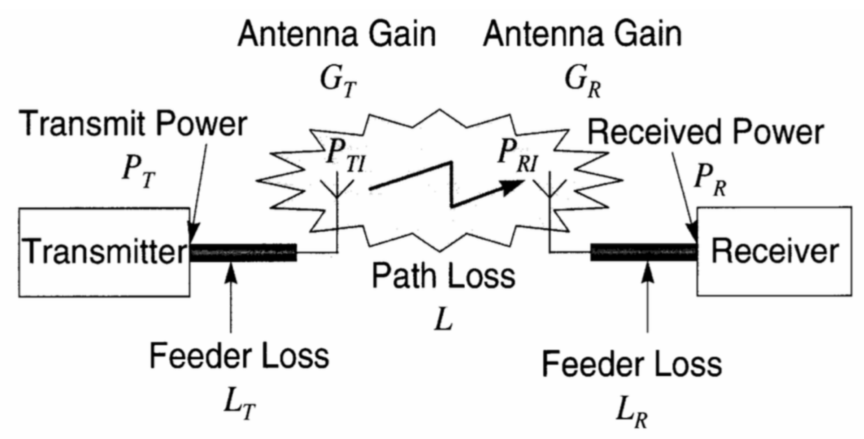


Figure 3.3: Block Diagram of Path Loss [41].

We have three kinds of models of path loss but in this section will be present:

1. Empirical models

2. Semi-deterministic models

3. Deterministic models

3.5.2 Path Loss Model

Due to the atmospheric absorption, the effect of path loss is greater at higher frequencies in mmWave communication [34]. It was discovered via empirical results and experiments which were carried out for mmWave systems of communication that a transmission of a signal at an antenna height of 7 meters will render a signal breakage originating at an exponent path loss of $\gamma = 3.73$ in 28 GHz. When considering different modulation techniques in studying its effects, we will have to take into account the path loss exponent value ranges of $\gamma = \{3,3.5, \dots 5\}$.

3.6 Empirical Models

Urban and suburban propagation is very complex in this method. There is an absence in description of coverage area like the description of all trees, buildings etc. Important parameter for cells designer: overall area covered. In this section we are going to discuss empirical propagation models for instance Okumara and Hata Models [42].

In the presence of the two empirical propagation models, we have Okumura and Hata. Free space loss and plane earth loss basic propagation models demand knowledge of location and constitutive parameters. The knowledge is also required in building terrain features with the need of coverage for every tree and terrain. Using an empirical model, we can account for complex effects that would otherwise be too complex to be practical or would need a provision of an unnecessary amount of detail. Amongst the many empirical prediction models, we have the Okumura and Hata model [42].

3.6.1 Okumura Propagation Model

In mobile communications, a signal determination for the receiver is highly significant between the receiver terrain as well as the transmitter terrain. Urban areas use Okumura model as one of the popular models to relay signal transmission. The application of the model is carried out for frequencies in between the ranges of 150 MHz to 1920 MHz and also for a separation distance that ranges from 1-100 km with heights of the antenna ranging from 30 -1000 m.

The path loss is provided in the following equation:

$$L_p\ (dB) = L_F + A_{mu}(f, d) - G(h_{te}) - G(h_{re}) - G(AREA) \qquad (3.1)$$

Where,

L_p represents a mid-value with propagation of path loss and L_F represents a loss of propagation in free space. A_{mu} is the mid-attenuation that has relativity to free space. Finally, $G(h_{te})$ represents a gaining factor in the height of the antenna for the station coinciding with the base, $G(h_{re})$ represents a gaining factor in the height of the antenna for the mobile and $G(AREA)$ represents a gain that is dependent to the environment type.

3.6.2 Hata's Propagation Model

To measure the frequency range between 150 MHz to 1500 MHz we can use the Hata model. The median path loss from the Hata is provided as:

$$L_p\ (urban)(dB) = 69.55 + 26.16 \log_{10} f_c - 13.82 \log_{10} h_{te} - \propto (h_{re}) + (44.9 - 6.55 \log_{10} h_{te}) \log_{10} d \qquad (3.2)$$

Where,

f_c represents a frequency range starting at 150-1500 MHz. h_{te} represents a station with a base coinciding with the height of the antenna that is effective and has ranges starting at 30-200 m· h_{re} represents a receiver that is effective and receipts a height (mobile) of an antenna that has ranges starting at 1-10 m. $\propto (h_{re})$ represents an effective factor of correction for the antenna in mobile and d is represents a distance in km resulting between a transmitter an also a receiver.

The mobile antenna correction factor for a large city is given by

$$\propto (h_{re}) = 8.29(1.1 \log_{10} 1.5\, h_{re})^2 - 1.1\ dB \text{ for } f_c \leq 300\text{MHz} \qquad (3.3)$$

$$\propto (h_{re}) = 3.2(1.1 \log_{10} 1.5\, h_{re})^2 - 4.97\ dB \text{ for } f_c \geq 300\text{MHz} \qquad (3.4)$$

The formula for the correction factor for antenna in the mobile for small city to a medium city is given as:

$$\propto (h_{re}) = (1.1 \log_{10} f_c - 0.7)\, h_{re} - (1.56 \log_{10} f_c - 0.8) \qquad (3.5)$$

The path loss formula for a model of Hata in an area that is a suburb is given as:

$$L_p(dB) = L_p\,(urban) - 2\{\log_{10}\left(\frac{f_c}{28}\right)\}^2 - 54 \qquad (3.6)$$

The path loss formula for the rural areas that are open is given as:

$$L_p(dB) = L_p(urban) - 4.78(\log_{10} f_c)^2 + 18.33 \log_{10} f_c - 40.94 \qquad (3.7)$$

Using the Hata model we can predict the mean signal path loss for the separation of transmitter receiver greater than 1Km. For this reason, it is much conducive for the bigger mobile phones, rather than the personal communication systems (PCS, radius<1km).

3.7 Omnidirectional Path Loss Model

A radio-engineer requires a transmit of a signal in all directions in order to determine the total accumulated power in a specific detached Transmitter-Recipient (T-R) by the omnidirectional path loss models, as obtained from two isotropic transmitting antennas, that transmit and receive in all directions with a gain of 0dBi. Parameters such as antenna beam width, frequency, distance and height of the transmitter and receiver could be used to describe path loss that transmits and receives in all directions. Measured path losses (distances in log-scale), WINNER II and 3GPP spatial channel models (SSCMs) could be determined by scaling up Minimum Mean Square Error (MMSE) approximate suitable line to give path loss model transmission in all directions that are scientifically bound and suits every possibility of calculated separations.

Without anchor point constraint, the floating intercept model could thereby relatively be determined. To obtain physical knowledge into characteristics of channel propagations relative to free space propagation, subroutine could be used as a piece of adjacent free space reference distance model to defy the floating-intercept model that in principle renders a more conducive minimal error feedback appropriate in determining path loss. In order to determine and examine the realism of next generation mmWave, extended 28 GHz and 73 GHz measurement of broadband propagation were established in New York City.

The examinations are a necessity in creating different transmission models which record the demand of size increment in RF bandwidths, creating mmWave spatial channel and determining the carrier frequency that is necessary to match the prominent spread for a quickened rate of information [43], [44].

The next generation wave radio-system design is embedded within 28 GHz and 73 GHz transmission path loss models. This model clearly shows that the NLOS (Path loss that results when the T_X side and R_X side are separated by blockage and therefore no connection between antennas could be established) path loss examples of 28 GHz and 73 GHz are the same and could be represented n = 3.4. The millimeter waves delegates for the 28 GHz and 73 GHz in both the T_X side and R_X side, that is greater than the known Microwave/UHF channels. Nowadays beam combining and forming technologies are used in portable cell phones that use antenna arrays that are electrically embedded on chip and utilize mmWave directional path loss to secure the slim direction of power reception [16].

Chapter 4

PERFORMANCE ANALYSIS BASED ON SIMULATION

4.1 Introduction

This chapter is about the implementation of different modulations (FSK, PSK and QAM) under various set ups. MATLAB 2017 has been used to simulate the results under different scenarios.

4.2 Implementation Set up

In this chapter, the performance of non-coherent FSK, PSK and QAM is studied based on simulation results. The simulations model the effects of the hardware impairments and channel distortion on the mentioned modulations. Different modulation sizes (i.e. M's which can be 4, 16, and 64) for non-coherent FSK and other modulations are examined.

According to Shannon's theorem, gives an upper bound to the capacity of a link, in bits per second (bps), as a function of the available bandwidth and the signal-to-noise ratio of the link and there is more data rate in higher frequency. The Theorem can be stated as:

$$c = B \times \log 2(1 + \frac{S}{N}) \tag{4.1}$$

Where, C is the achievable channel capacity, B is the bandwidth of the line, S is the average signal power and N is the average noise power. The signal-to-noise ratio (S/N) is usually expressed in decibels (dB) given by the formula:

$$10 \log 10 \left(1 + \frac{S}{N}\right) \tag{4.2}$$

Next generation cellular networks have to support a significantly larger number of users. To meet this demand on higher data capacity and higher data rates, 5G networks must take advantage of the frequencies in the mmWave.

For modeling small scale fading, the Rician factor is settled to $K_R = 5$ in dB. The angle of arrival θ is considered as a uniformly distributed random variable in the range of 0 to 2π. On the other hand, for the large scale fading, the reference distance is considered as $d_o = 1$m and the distance between transmitter and receiver antennas i.e. d is assumed to be 25m. The large scale parameter is set as follows: path loss exponent γ is equal to 4 with the carrier frequency $f_c = 60GHz$ for the modulators. The average symbol power $P = Ex_n \{|x_n|^2\}$ is set to 1. In order to have a constant ratio of energy per bit to the spectral noise density, the density for noise power (N_o) is set in comparison to the energy per bit(E_b), unless stated otherwise.

Total loss is calculated by $L_t = \gamma \; 10 \log_{10} \frac{d}{d_0} - 10 \log_{10} K_R \; (f_c)$. Therefore, with the parameters above i.e. $L_t = 124 \; dB$. Thus, $\frac{E_b}{N_o}$= 150 dB at the sender is converted to $26 \; dB$ at the receiver, if the signal reduction due to f_c and γ is neglected (as it is assumed in many researches). All results are simulated under Monte-Carlo averaging with 10^5 iterations with 100 symbols frame's length.

4.3 Effect of Phase Noise

For the fixed value of phase noise variance $\sigma_{phn}^2 = 10^{-3}\ rad^2$, the Bit Error Rate (BER) versus $\frac{E_b}{N_o}$ is depicted in Figure 4.1. In this figure, the range of values of $\frac{E_b}{N_o}$ from 1 to 31 dB with the step size of 5 is considered. Note that the attenuation of the 124 dB by the signal results from the frequency of the carrier $f_c = 60GHz$, path loss exponent $\gamma = 4$ and $d = 25m$.

Accordingly, $\frac{E_b}{N_o} = \{125, 130, \dots, 155\}\ dB$ at the transmitter is converted to the range of $\{1, 6, \dots, 31\}\ dB$ at the receiver point with the effect of phase noise. Moreover, other hardware distortion noise variance parameters such as shadowing parameter $\sigma_{shad} = 9rad^2$ and $\sigma_{nl}^2 = 0.2\ rad^2$ are constant. We will see the effect of these hardware distortions on BER in the following sections.

In general, it can be seen that BERs of all FSK modulations (for M=4,16, and 64) reduce steadily by increasing $\frac{E_b}{N_o}$. It can be observed from Figure 4.1 that FSK modulations with M=4 and M=16 have BER less than 10^{-2} (even approaching to 10^{-3}) at $\frac{E_b}{N_o} = 31\ dB$. This phenomenon is not seen for PSK and QAM modulations (they do not reduce to less than 10^{-2}). Although that FSK modulation with M=64 is not below 10^{-2} at $\frac{E_b}{N_o} = 31\ dB$, due to the slope of the curve it can be seen that it has same behavior as FSK modulations with M=4, and 16 and BER will reduce in higher $\frac{E_b}{N_o}$'s than 31 dB. In case of that QAM modulation with M=4, in spite of having less than 10^{-2} BER after almost $\frac{E_b}{N_o} = 16dB$, similar to other QAM modulations, it is flattened out at a specific BER by increasing in $\frac{E_b}{N_o}$ after a while.

Another observation is that BER, in case of utilizing FSK, is increased by increase in M. However, if the modulation size M is set as 4 i.e. 4-FSK, it needs only 4 times larger bandwidth in comparison with the one required by PSK or QAM modulation for the same modulation order.

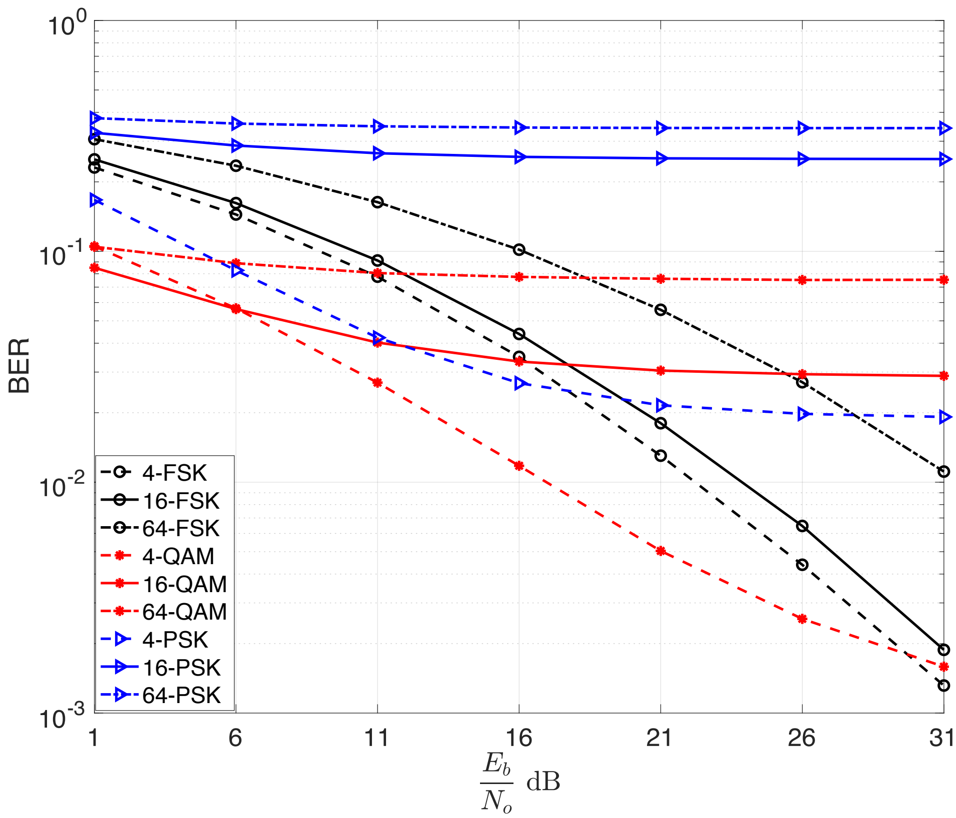


Figure 4.1: BER versus $\frac{E_b}{N_o}$ ($\sigma_{phn}^2 = 10^{-3}$, $f_c = 60$ GHz, $\gamma = 4$, $\sigma_{nl=}^2$ 0, $\sigma_{shad} = 9$).

The influence of phase noise variance (σ_{phn}^2) within the range of 10^{-4} to 10^{-1} with the step size of 10 is depicted in Figure 4.2. Generally speaking, according to Figure 4.1 the application of PSK, QAM and FSK are approaching to the same BER i.e.

almost 10^{-1} in the energy per bit range from $\frac{E_b}{N_o} = 1\ dB$ to $6\ dB$. It is seen that the PSK modulation cannot have a better BER less than 10^{-2}; same situation happens for the QAM modulation with M=16, and 64.

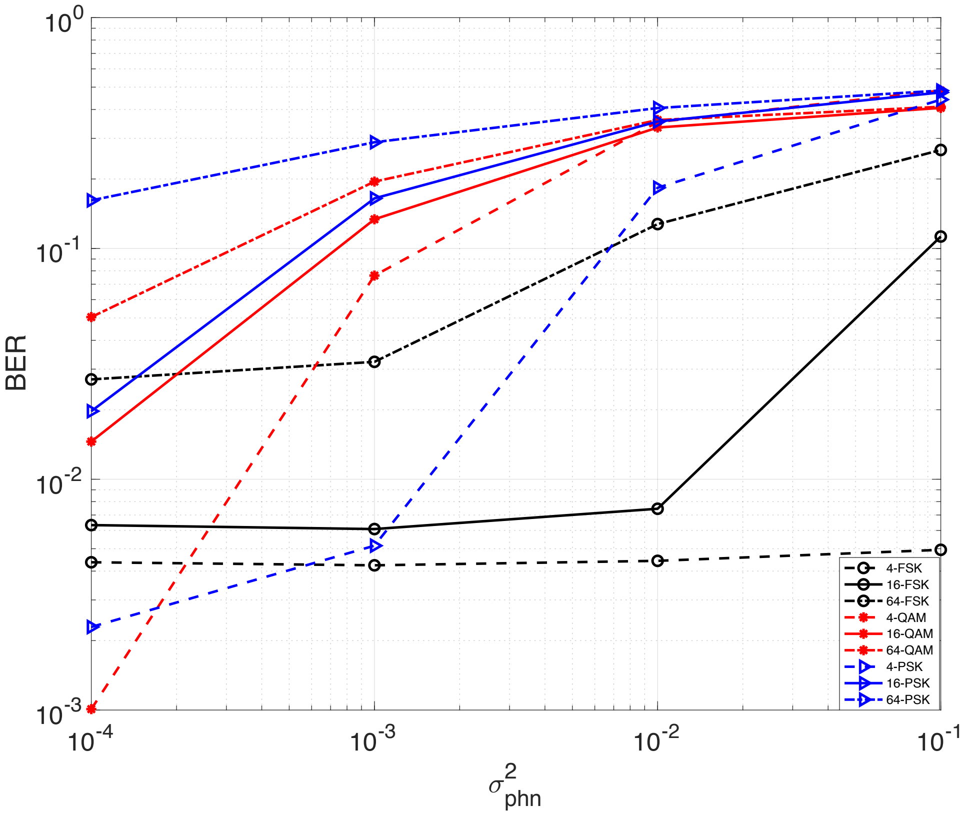


Figure 4.2: BER versus σ^2_{phn} at $\frac{E_b}{N_o}$ = 26 dB, f_c = 60 GHz, γ = 4, σ^2_{nl} =0, σ_{shad} = 9.

Figure 4.2 is describing the evaluation of phase noise effect on BER when $\frac{E_b}{N_o}$ is kept at $26\ dB$. As it can be seen, FSK is less affected by stronger phase noise amounts (e.g. $\sigma^2_{phn} = 10^{-2}\ rad^2$) in compare with both PSK and QAM modulations.

4.4 Effect of Other Hardware Distortions

Up to this section, we discussed the efficiency of FSK, PSK and QAM modulations with different values of $\frac{E_b}{N_o}$ and σ^2_{nl}. Now the performance of these modulation utilizations is studied with $\sigma_{shad} = 0$. For doing this, the changes in BER versus different values of $\frac{E_b}{N_o}$ are studied at the fix value of σ_{nl}^2= 0.2.

In Figure 4.3, it can be seen that the effect of impairments hardware has same effect on both PSK and FSK (except 4-FSK) modulations, the BER suffers from an error floor and BER cannot be less than 10^{-2} even at $\frac{E_b}{N_o}$ =31 dB, whereas BER with the using of QAM is reached to less than 10^{-3} at $\frac{E_b}{N_o}$ =31 dB. On the other hand, BER for the 4-FSK has better performance in compare with other modulations.

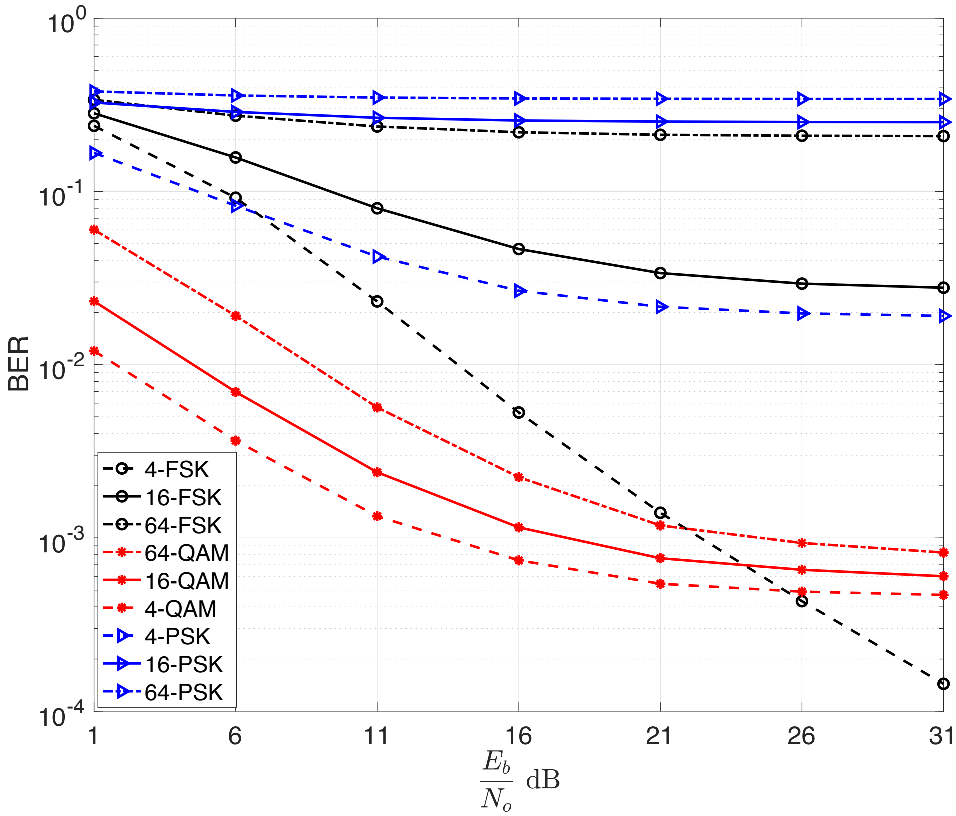


Figure 4.3: BER versus $\frac{E_b}{N_o}$ at the receiver with $\sigma_{nl}^2 = 0.2$, $\sigma_{phn}^2 = 0$, f_c = 60 GHz, γ = 4, $\sigma_{shad} = 0$.

As expected, BER in case of using both PSK and FSK is increased by increasing of modulation from M=4 to M=64. BER is increased by increasing in size of modulation M from 4 to 64 in case of utilizing QAM modulation, not considerably thought.

Figure 4.4 shows the effect of distortion noise variance σ_{nl}^2 from 0.05 to 0.3, with the step of 0.05, on BER while $\frac{E_b}{N_o}$ is kept at 26 dB. It can be seen that the hardware distortion noise variance is not very affecting on 16-PSK, 64-PSK, and 64-FSK modulations; in these configurations, BER fails to achieved less than 10^{-1} even at σ_{nl}^2=0.3 (however, both 4-PSK and 16-FSK have BERs less than 10^{-1}). In case of 4-FSK, the hardware distortion noise variance σ_{nl}^2 is not very effective on BER although 4-FSK has the minimum BER in general, especially for the σ_{nl}^2 's more than 0.25.

As it can be seen, in case of utilizing QAM, BER is less than 10^{-4} in the range of σ_{nl}^2 from 0.05 to 0.1. However, BER is generally increased by increasing of σ_{nl}^2 especially with faster pace for σ_{nl}^2 more than 0.1.

Considering the size of modulation, BER increases by increasing in M-FSK and M-PSK and also, in QAM modulation BER increases by increasing M. Additionally, in this part the QAM has a better performance to compare other modulation techniques except in compare to 4-FSK with the σ_{nl}^2 more than 0.2.

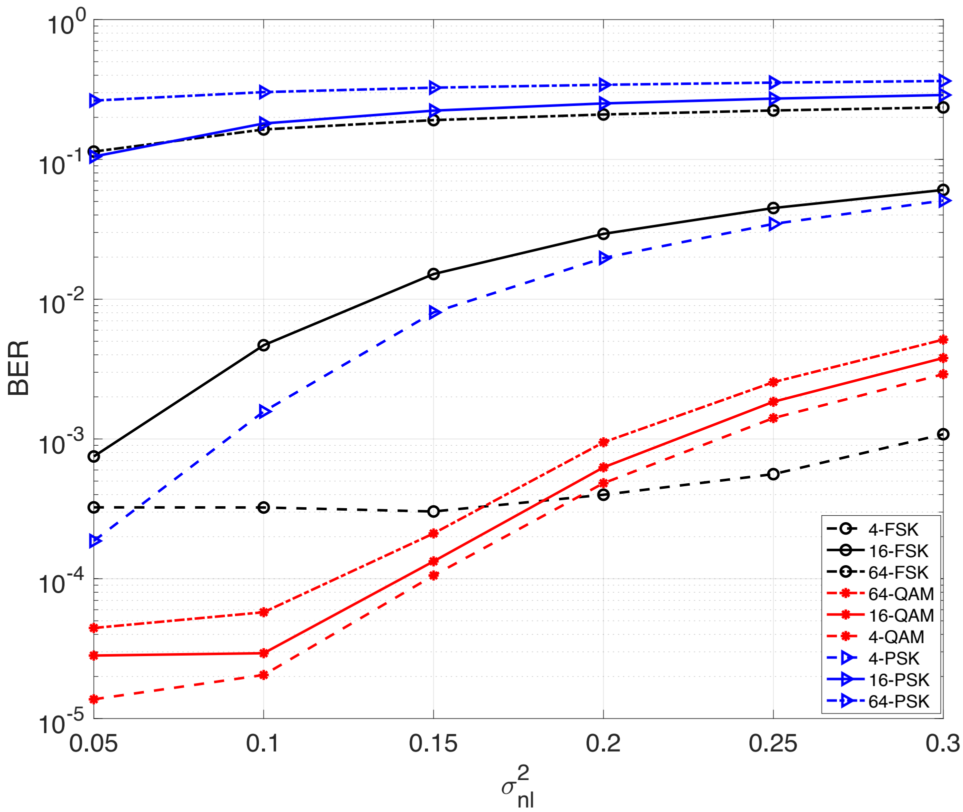


Figure 4. 4: BER versus σ_{nl}^2 at $\frac{E_b}{N_o}$ = 26 dB at the receiver,$\sigma_{phn}^2 = 0$, f_c = 60 GHz $\gamma = 4$, $\sigma_{shad} = 0$.

4.5 Effect of Large Scale Channel Fading

In this section, we carry out a study of the effects of three parameters of fading in large scale including, carrier frequency, shadowing and path loss exponent on different types of modulation techniques.

4.5.1 Effect of Shadowing Distortion Standard Deviation on BER

Figures 4.5.1 and 4.5.2 depict the changes of BER w.r.t. to shadowing standard deviation (σ_{shad}). For the sake of simplicity, only two sizes of modulation (M=16 and M=64) are considered. Moreover, $\frac{E_b}{N_o}$ has been kept at 26 dB at the receiver (150 dB at the transmitter).

We set the shadowing-standard deviation range from 0dB to 12dB with the step of 3dB. The parameters used in Figure 4.5.1 are set similar to the ones used in Figure 4.1 and the parameters used in Figure 4.5.2 are set similar to the ones used in Figure 4.3.

As it can be seen in Figure 4.5.1 in general, FSK modulation has lower level of BER in compare to both QAM and PSK modulations. Moreover, by increasing the size of modulation from 16 to 64 the BER on all of the modulations increases. The effect of shadowing on BER in both PSK and QAM modulations are very narrow that can be neglectable whereas, in case of FSK it changes BER dramatically from below 10^{-3} to over 10^{-2}. At $\sigma_{shad} = 9dB,$ 16-FSK has the minimum BER in compare with the other configurations.

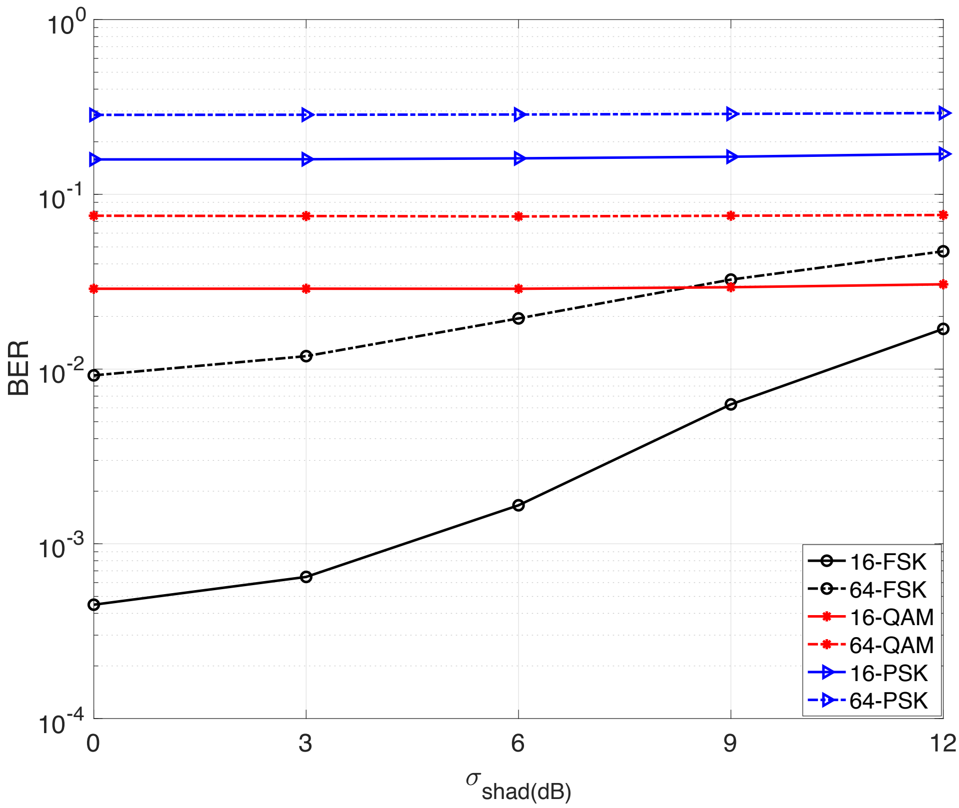


Figure 4.5.1: BER versus phase noise variance $\sigma_{phn}^2 = 10^{-3}$ at $\frac{E_b}{N_o} = 26$ dB at the receiver. f_c = 60 GHz, γ = 4, $\sigma_{nl}^2 = 0$.

In Figure 4.5.2 it is seen that in general QAM has much lower BER in compare with other configurations. As a matter of fact, the BER of a system employing M-PSK and M-QAM suffers from an error floor and the level of the error floor increases by increasing the modulation order M due to denser constellations. Moreover, with QAM modulation, BER is decreased by increasing in the size of modulations from 16 to 64, in contrast to PSK and FSK modulations. 16-FSK has lower BER in compare to 64-FSK, 16-PSK, and 64-PSK which have almost similar BER.

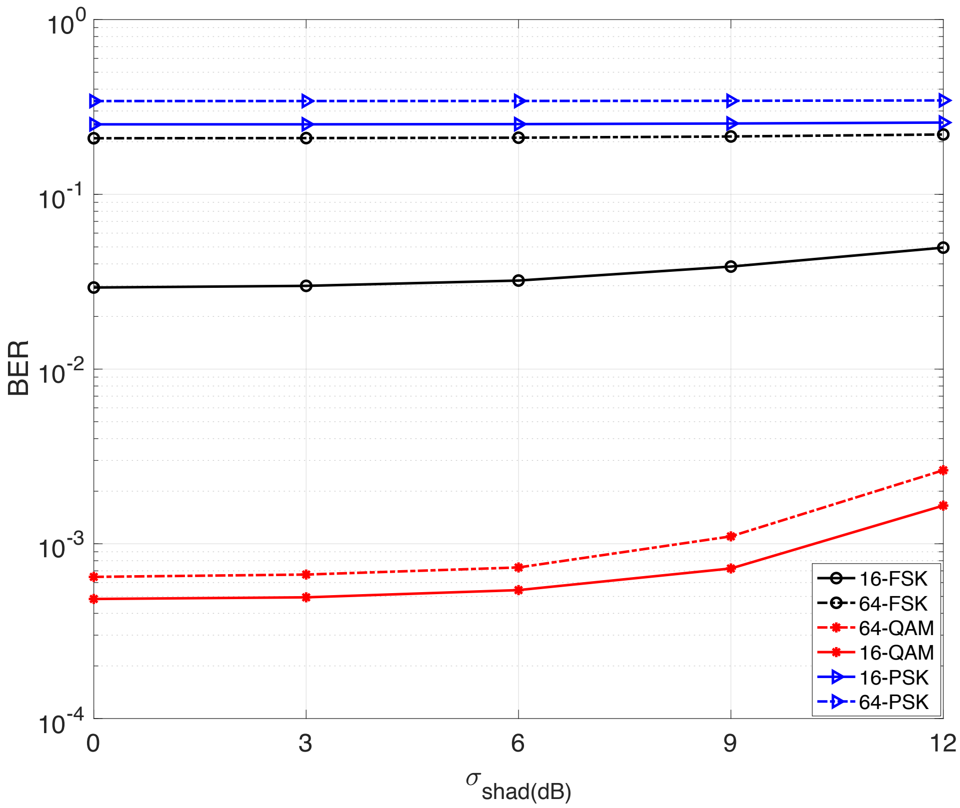


Figure 4.5.2: BER versus $\sigma_{phn}^2 = 0$ at $\frac{E_b}{N_o} = 26$ dB in receiver. $f_c = 60$ GHz, $\gamma = 4$. $\sigma_{nl}^2 = 0.2$.

4.5.2 Effect of Path Loss Exponent on BER

Figures 4.5.3, 4.5.4 and 4.5.5, show, the effect of path loss exponent on amount of BER. The studied range of γ is from 3dB to 5dB with step of 0.5dB. In Figure 4.5.3, σ_{nl}^2 and σ_{shad} are 0 and 9, in Figure 4.5.4 are 0.2 and 0, and in Figure 4.5.5 are 0.2 and 9 respectively.

As it can be seen in Figure 4.5.3 in general, FSK modulation has lower level of BER in compare to both QAM and PSK modulations for γ less than 4 dB. Moreover, by increasing the size of modulation from 16 to 64 the BER on all of the modulations increases. The effect of path loss exponent on BER in both PSK and QAM modulations are narrow whereas, in case of FSK it changes BER dramatically from far below 10^{-3} to far over 10^{-2}. For γ's more than 4.5 dB QAM has lower BER in compare to FSK.

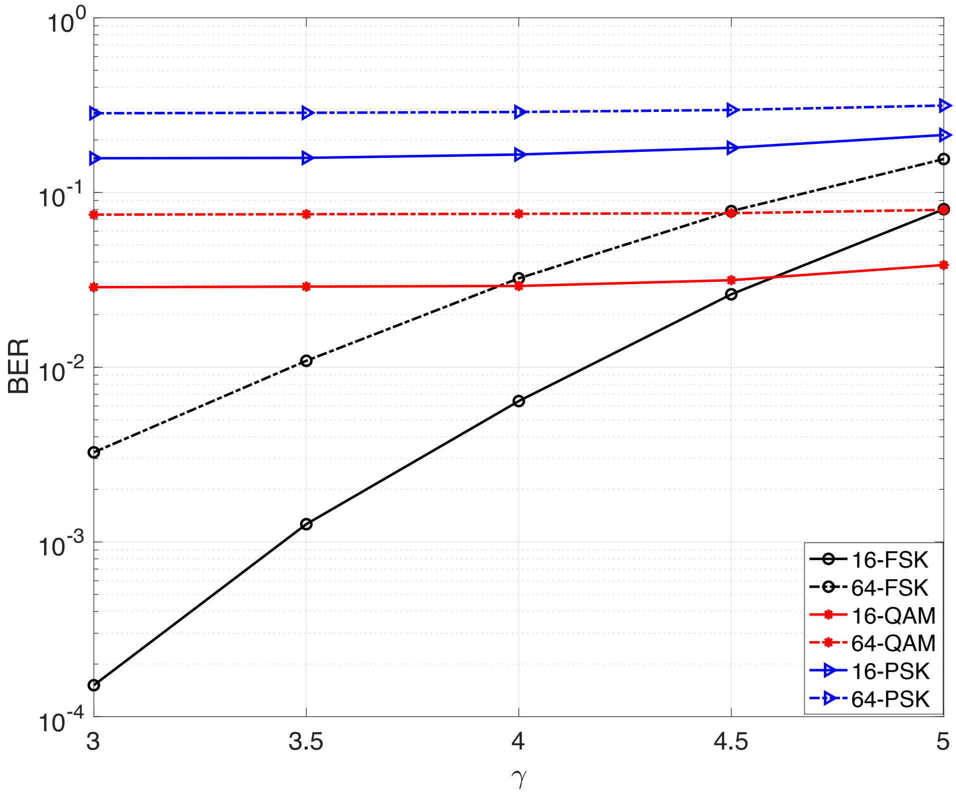


Figure 4.5.3: BER versus phase noise variance $\sigma^2_{phn} = 10^{-3}$ at $\frac{E_b}{N_o} = 26$ dB at the receiver. f_c = 60 GHz, σ^2_{nl} = 0, σ_{shad}= 9.

In Figure 4.5.4, similar to Figure 4.5.2, it is seen that in general QAM has much lower BER in compare with other configurations. Moreover, with QAM modulation, BER is increased by increasing the size of modulations from 16 to 64, in contrast to PSK and FSK modulations. 16-FSK has lower BER in compare to 64-FSK, 16-PSK, and 64-PSK which have almost similar BER.

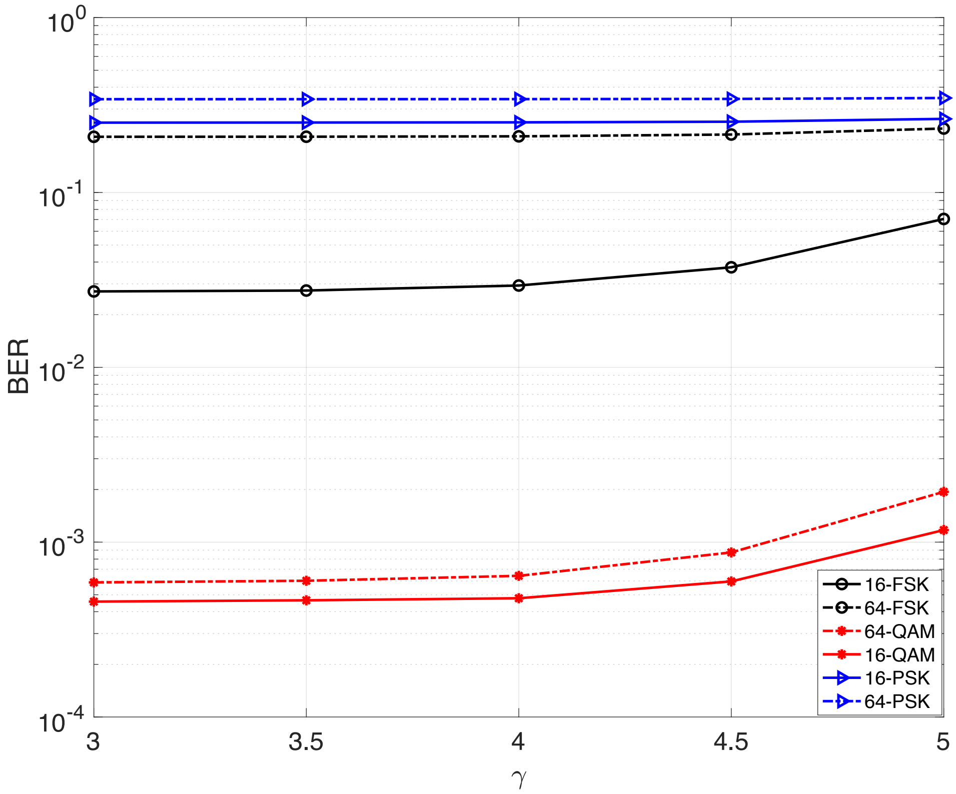


Figure 4.5.4: BER versus $\sigma_{phn}^2 = 0$ at $\frac{E_b}{N_o} = 26$ dB at the receiver. f_c = 60 GHz, σ_{nl}^2 = 0.2, σ_{shad} = 0.

Based on Figure 4.5.5, BER is not changed by altering γ except for 16-FSK. In this case we assume phase noise variance $\sigma_{phn}^2 = 10^{-3}$. It is noteworthy that in this configurations BER cannot be less than 10^{-2}. Moreover, almost all of them all around 10^{-1}.

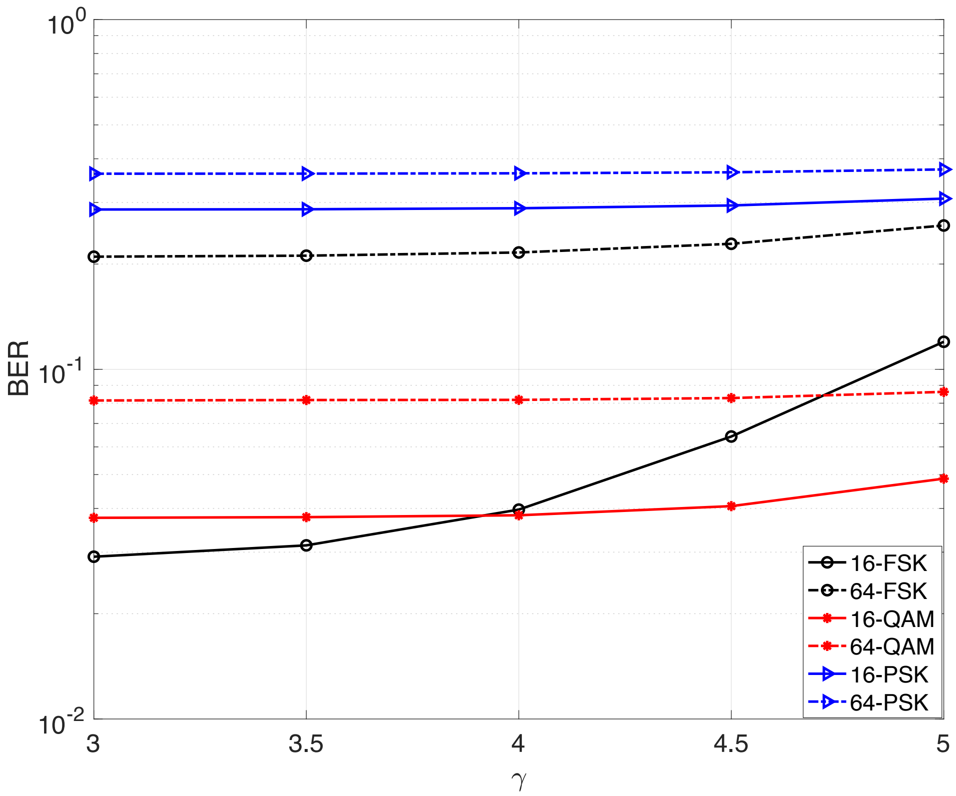


Figure 4.5.5: BER versus phase noise variance $\sigma^2_{phn} = 10^{-3}$ at $\frac{E_b}{N_o} = 26$ dB at the receiver. f_c = 60 GHz, σ^2_{nl} = 0.2, σ_{shad}=9.

4.5.3 Effect of Carrier Frequency on BER

Figures 4.5.6, 4.5.7 and 4.5.8, show, the effect of carrier frequency on amount of BER. The studied range of f_c is from 40GHz to 120GHz with step of 10GHz. The range of mmWave is from 30GHz to 300 GHz. For all the results, we assume that the value of path loss exponent is $\gamma = 4dB$ and the distance in between the transmitter and the receiver is assumed $d = 25\ meters$.

In Figure 4.5.6, σ^2_{nl} and σ_{shad} are 0 and 9, in Figure 4.5.7 are 0.2 and 0, and in Figure 4.5.8 are 0.2 and 9 respectively.

As it can be seen in Figure 4.5.6 similar to Figure 4.5.3, in general, FSK modulation has lower level of BER in compare to both QAM and PSK modulations (although for 64-FSK this is true for f_c less than 60GHz). Moreover, by increasing the size of modulation from 16 to 64 the BER on all of the modulations increases.

The effect of carrier frequency on BER in both PSK and QAM modulations are very narrow, but in case of FSK it changes BER dramatically from far below 10^{-2} to over 10^{-2}. For f_c 's more than 60GHz 16-QAM has lower BER in compare to 64-FSK.

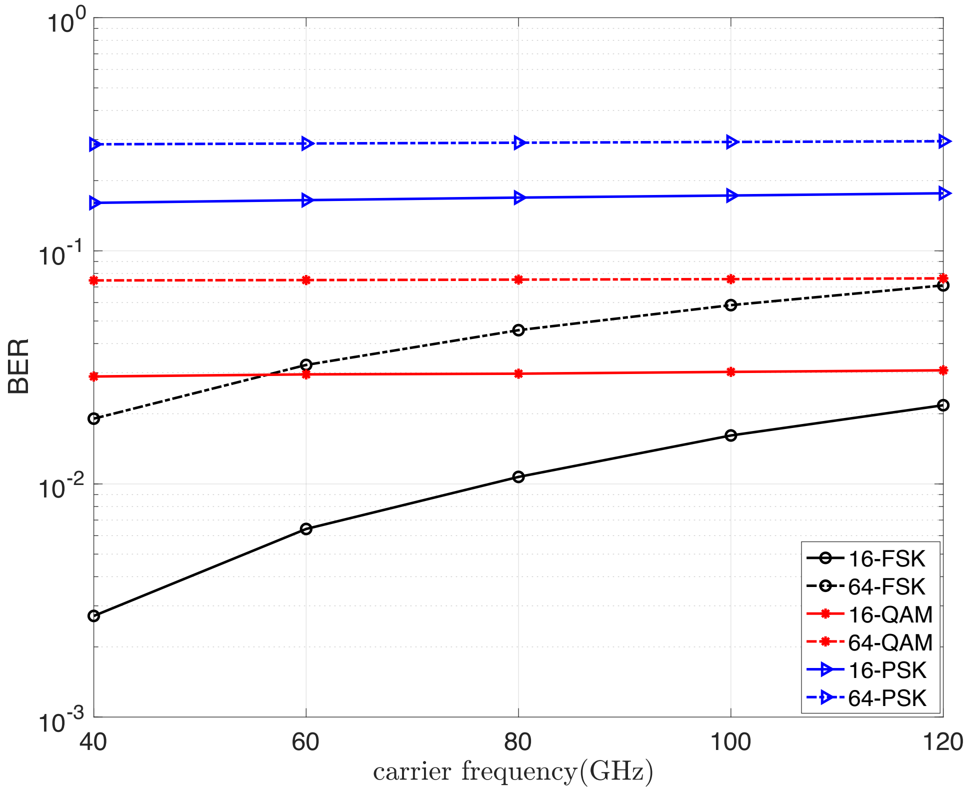


Figure 4.5.6: BER versus phase noise variance $\sigma_{phn}^2 = 10^{-3}$ at $\frac{E_b}{N_o} = 26$ dB at the receiver. γ=4, $\sigma_{nl}^2 = 0$, σ_{shad}= 9.

In Figure 4.5.7, similar to Figure 4.5.4, it is seen that in general QAM has much lower BER in compare with other configurations. Moreover, with QAM modulation, BER is increased by increasing in the size of modulations from 16 to 64, in contrast to PSK and FSK modulations. 16-FSK has lower BER in compare to 64-FSK, 16-PSK, and 64-PSK which have almost similar BER.

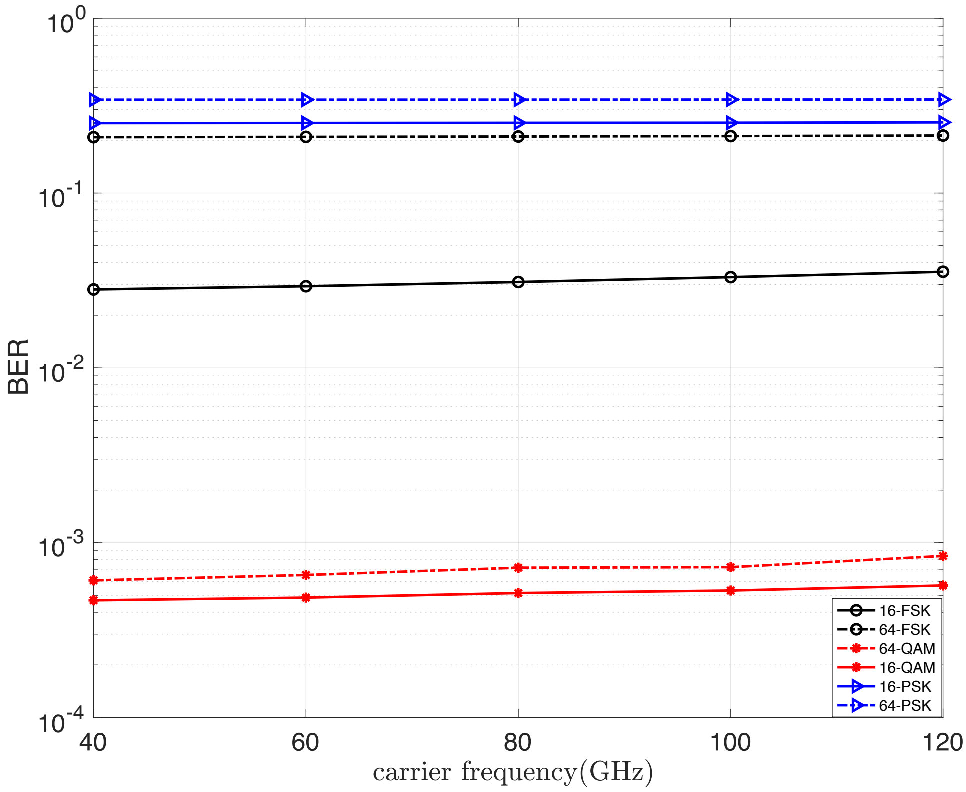


Figure 4.5.7: BER versus $\sigma_{phn}^2 = 0$ at $\frac{E_b}{N_o} = 26$ dB in receiver. $\gamma = 4$. $\sigma_{nl}^2 = 0.2$, σ_{shad}= 0.

Based on Figure 4.5.8, BER is not changing by altering f_c except for 16-FSK. In this case we assume phase noise variance $\sigma_{phn}^2 = 0$. it is noteworthy that in this configurations BERs cannot be less than 10^{-2}. Moreover, almost all of them all around 10^{-1}.

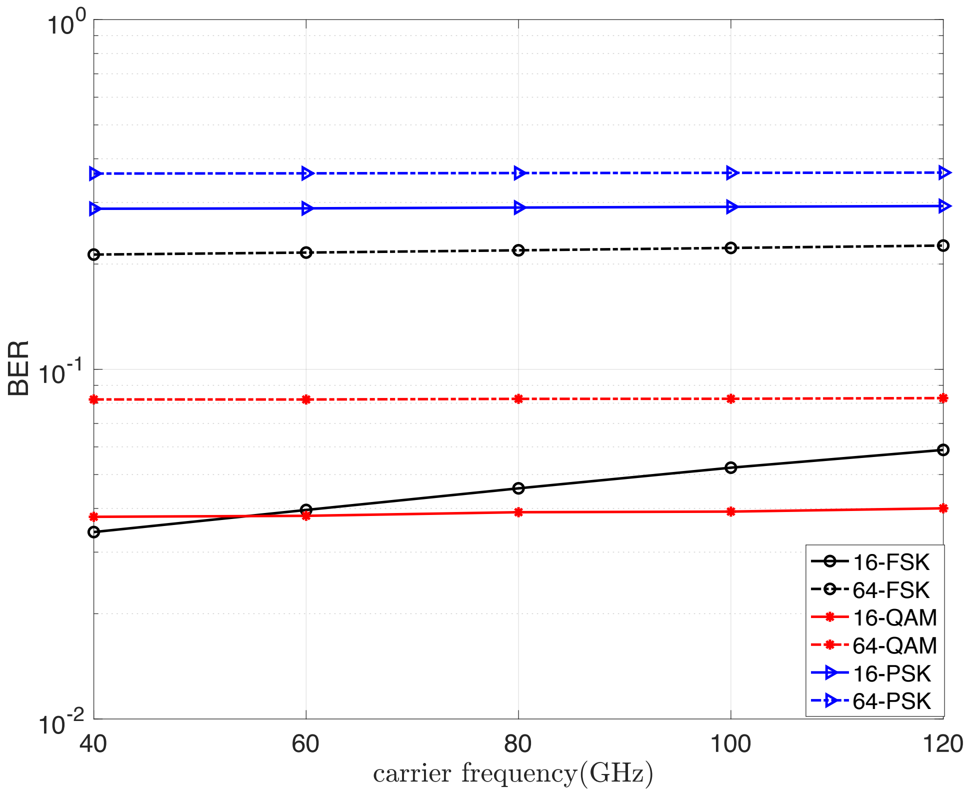


Figure 4.5.8: BER versu $\sigma_{phn}^2 = 10^{-3}$ at $\frac{E_b}{N_o}$ = 26 dB in receiver. γ = 4, σ_{nl}^2 = 0.2, σ_{shad}= 9.

4.6 Effect of Hardware Impairments and Channel Distortions

Figure 4.6 depicts the hardware impairments effects as well as the channel distortions on BER. Base on the system model described in section 2, we fix the parameters of hardware distortion noise variance (σ_{nl}^2) = 0.2, phase noise variance (σ_{phn}^2) = 10^{-3}, carrier frequency (f_c)= 60GHz, path loss exponent (γ) = 4 and shadowing-standard deviation (σ_{shad})= 9 dB. The range of $\frac{E_b}{N_o}$ is considered from 1dB to 41dB at the receiver.

As it can be seen in Figure 4.6, 4-FSK has less BER in compare with the other configurations, especially for $\frac{E_b}{N_o}$ more than 21dB. In general the size 4 for all modulations has less BER in compare to other sizes in each modulation. The changes in $\frac{E_b}{N_o}$ are more effectives on 4-FSK for $\frac{E_b}{N_o}$ more than 16dB.

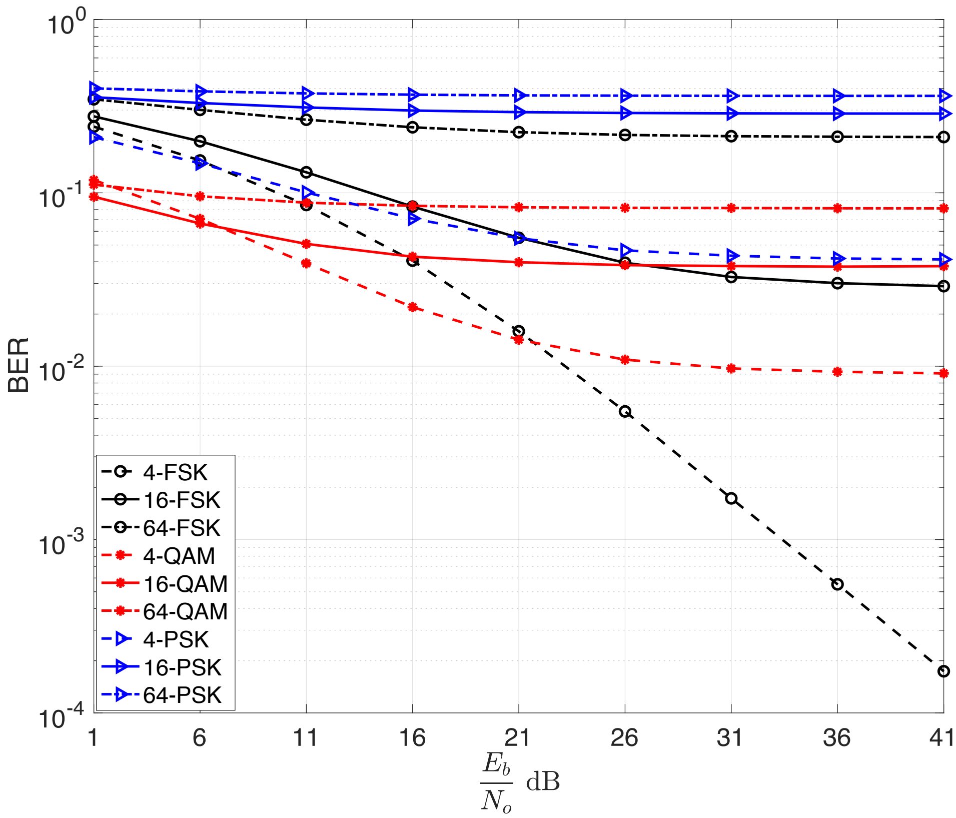


Figure 4.6.1: BER versus $\frac{E_b}{N_o}$ = {1,6,…,41} dB at the receiver, $\sigma_{phn}^2 = 10^{-3}$, $(\sigma_{nl}^2\ ) =$ 0.2 , f_c = 60 GHz γ = 4, σ_{shad}= 9.

Chapter 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

In this thesis, an inclusive outline and demonstration of various cellular wireless networks together with the advent of the new generation (5G) and all the Pros and Cons were fully discussed. It has provisioned a clear description that seeks to merge newly discovered signal transmission technology with the upcoming 5G technology. For instance, a frequency band of 30 GHz up to 300 GHz gives way to the transmission of greater amounts of data in just the shortest time possible.

Using an intensive system-level simulation, we have clearly illustrated the important benefit of applying non-coherent FSK in comparison to different modulations techniques, for example phase shift keying and Quadrature amplitude modulation in 60 GHz band in the availability of channel distortions as well as hardware impairments.

There is an imminent eradication of severely affected path loss, non-linearity amplifier, shadowing and phase noise in a much more improved way when compared to other modulation schemes such as QAM and PSK. Individually putting into consideration, the side effects of impairments of the hardware (phase noise depicted in Figure 4.1 and non-linearity amplifier in Figure 4.3), our extra intensive simulation translate that the BER in 4-ary non-coherent FSK is 100 times smaller when we compare it to the BER in 4-PSK or 4-QAM at the receiver $\frac{E_b}{N_o}$ is equal to 31 dB. Our extra intensive simulation also demonstrates the channel distortions individually (shadowing in Figure 4.5.1 to Figure 4.5.2 and path loss in Figure 4.5.3 to Figure 4.5.4 having to consider BER in 16-ary-non-coherent FSK is roughly 1.57 and 2.3 times smaller when we compare it to the BER for 16-PSK or 16-QAM in receiver $\frac{E_b}{N_o}$ is equal to 26 dB.

Having to put into consideration the outcome of the totality of the hardware and channel impairments hand in hand (Figure 4.6), our extra intensive simulation depicts that BER in 4-ary non-coherent FSK is roughly smaller in comparison to the BER in 4-PSK or 4-QAM at receiver $\frac{E_b}{N_o}$ = 41dB. This translated, means the combination of BER with low complexity for detection for FSK non-coherent is making BER a more attractive suitable modulation technique for attaining multiple-Gbps with wireless links at mmWave frequencies.

5.2Future Work

Having not considered having to code or carry out any receiver design for the reimbursement of the effect of hardware non-linearities, the subject of future research is dependent on comparing the performance of dissimilar modulation schemes.

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