CHANNEL MODELLING OF 5^{TH} GENERATION COMMUNICATION TECHNOLOGY

Project report submitted in partial fulfilment of the requirement for the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

SAKET KUMAR	**121078**
SHSHANK PANDEY	**121079**
NIPUN THAKUR	**121081**

UNDER THE GUIDANCE OF

DR.GHANSHYAM SINGH

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY, WAKNAGHAT

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DECLARATION BY THE SCHOLAR

I hereby declare that the work reported in the B-Tech thesis entitled "Channel modelling of 5th generation Communication technology" submitted at Jaypee University of Information Technology, Waknaghat India, is an authentic record of my work carried out under the supervision of Dr.Ghanshyam Singh. I have not submitted this work elsewhere for any other degree or diploma.

Saket kumar. Shshank Pandey

Saket Kumar ShshankPandey Nipun Thakur

Department Of Electronics and communication Engineering

Jaypee University of Information Technology, Waknaghat, India

Date :

SUPERVISOR'S CERTIFICATE

This is to certify that the work reported in the M-Tech. thesis entitled "Channel modelling of fifth generation (5G) Communication technology", submitted by Saket Kumar, Shshank Pandey and Nipun Thakur at Jaypee University of Information Technology, Waknaghat, India, is a bonafide record of his / her original work carried out under my supervision. This work has not been submitted elsewhere for any other degree or diploma.

DR. GHANSHYAM SINGH

PROFESSOR

DATE:

ACKNOWLEDGEMENT

We have taken efforts in this project. However, it would not have been possible without the kind support and help of Dr. Ghanshyam Singh. We would like to extend our sincere thanks to him.

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LIST OF SYMBOLS & ACRONYMS

Z: Signal transmitted over the channel comprising both in-phase and quadrature components.

Pz(z): Probability distribution function of signal transmitted over a channel.
p_r: Average received signal power.

σ^2: Half of the average power in the non-LOS multipath components.

s^2: Power in the LOS component.

k: Fading parameter, ratio of power in LOS component to the power in non LOS component.

M: Fading parameter in Nakagami distribution.

s(t): Transmitted signal over the channel.

X_i: The Generalized-K distributed signal envelop.

f_x(x): Probability distribution function of generalized K distributed signal envelop.

x: Support.

l: Number of branches in the receiver.

K_{k-ml}: Modified Bessel function of order k-ml.

Ω: Mean power of the signal.

γ: Signal to noise ratio.

α: ml+k-1.

β: k+ml.

M(s): Moment generating function.

M(s,a): Marginal moment generating function.

LIST OF FIGURES

SUMMARY

There are continuous efforts to optimize mobile communications networks, in order to get the maximum performance out of them. Accurate radio channel knowledge is crucial to do this well. When optimizing network performance, it is very important that the modelling of the radio channel directional characteristics is realistic and not over-simplified.

Direct device-to-device communication, an important area for 5G, presents one challenging scenario from a radio propagation perspective: dual link end mobility. Both ends of the link may be moving, which is in contrast to standard cellular communications where the base station end of the link is fixed. Another scenario is radio communication through crowds, where a large number of people may move around and temporarily block the radio link.We have discussed some of the major technologies we are going to use in channel modelling.

MIMO systems consist of multiple antennas at both the transmitter and receiver. By adding multiple antennas, a greater degree of freedom in wireless channels can be offered to accommodate more information data in massive MIMO systems, the transmitter and/or receiver are equipped with a large number of antenna elements (typically tens or even hundreds). A massive MIMO system can also significantly enhance both spectral efficiency and energy efficiency. Next generation wireless technology that can provide up to multi - Gbps wireless connectivity. Data rate is expected to be 40-100 times faster than today's wireless LAN technologies. Frequency range is from 25GHz to 300GHz.Based on the principle of line of sight (LOS) paths. It is required to use reflective paths by many object.

In wireless communications, fading is deviation of the attenuation affecting a signal over certain propagation media. The fading may vary with time, geographical position or radio frequency, and is often modelled as a process. The Rayleigh distribution is the distribution of the magnitude of a two-dimensional random vector whose coordinates are independent, identically distributed, mean normal variables. The distribution has a number of applications in settings where magnitudes of normal variables are important.

Rician fading is a stochastic model for radio propagation anomaly caused by partial cancellation of a radio signal by itself — the signal arrives at the receiver by several different

paths, and at least one of the paths is changing .Rician fading occurs when one of the paths, typically a line of sight signal, is much stronger than the others.Refined model for the pdf of a signal amplitude exposed to mobile fading . The sum of multiple independent and identically distributed Rayleigh-fading signals have a Nakagami distributed signal amplitude. It is the effect that the received signal power fluctuates due to objects obstructing the propagation path between transmitter and receiver. These fluctuations are experienced on local-mean powers, that is, short-term averages to remove fluctuations due to multipath fading.

The received signal over a wireless channel is usually characterized by the joint effect of two independent random processes such as small scale fading due to the arrival of multiple, randomly delayed, refracted, reflected and scattered signal components at the receiver and large scale fading due to the shadowing from various obstacles in the propagation path.In addition to the multipath fading in the wireless environment, the quality of signal is also affected due to the shadowing from various obstacles in the propagation path.

Capacity analysis over the Generalized-K fading environment with L-branch MRC diversity. The main contribution of this paper consists of the evaluation the MMGF and the derived mathematical expression for MMGF is used to obtain a closed-form expression for the channel capacity under optimal rate adaptation with constant transmit power (ORA) and channel inversion with fixed rate (CIFR). The derived results are generic and applicable to other type of fading. We have proposed the moment generating function (MGF) based approach has been proposed for the computation of the channel capacity only for CORA scheme by using the numerical techniques. A MGF based approach is developed for the evaluation of channel capacity for several rate adaptations and transmit power schemes.

Using the above given equations and many more. We will be able to model a channel for 5G communication system implying all the effects of shadowing, fading (Nakagami), and all other technologies used, using Marginal Moment Generating Function as the basi

CHAPTER 1

INTRODUCTION

1.1 Various generations of mobile communication

1.1.1 First generation

1G refers to the first generation of wireless telephone technology (mobile telecommunications). These are the analog telecommunications standards that were introduced in the 1980s and continued until being replaced by 2G digital telecommunications. The main difference between the two mobile telephone systems (1G and 2G), is that the radio signals used by 1G networks are analog, while 2G networks are digital. The First generation of wireless telecommunication technology is known as 1G was introduced in 1980.

The main difference between then existing systems and 1G was invent of cellular technology and hence it is also known as First generation of analog cellular telephone. In 1G or First generation of wireless telecommunication technology the network contains many cells (Land area was divided into small sectors, each sector is known as cell, a cell is covered by a radio network with one transceiver) and so same frequency can be reused many times which results in great spectrum usage and thus increased the system capacity i.e. large number of users could be accommodated easily.

One such standard is NMT (Nordic Mobile Telephone), used in Nordic countries, Switzerland, the Netherlands, Eastern Europe and Russia. Others include AMPS (Advanced Mobile Phone System) used in North America and Australia,[TACS (Total Access Communications System) in the United Kingdom, C-450 in West Germany, Portugal and South Africa, Radiocom 2000[in France, TMA in Spain, and RTMI in Italy. In Japan there were multiple systems. Three standards, TZ-801, TZ-802, and TZ-803 were developed by

NTT (Nippon Telegraph and Telephone Corporation), while a competing system operated by DDI (DainiDenden Planning, Inc.) used the JTACS (Japan Total Access Communications System) standard.

Analog Signals does not allow advance encryption methods hence there is no security of data i.e. anybody could listen to the conversion easily by simple techniques. The user identification number could be stolen easily and which could be used to make any call and the user whose identification number was stolen had to pay the call charges. Analog signals can easily be affected by interference and the call quality decreases.

1.1.2 Second generation

2G is short for second-generation wireless telephone technology. Second generation 2G cellular telecom networks were commercially launched on the GSM standard in Finland by Radiolinja (now part of Elisa Oyj) in 1991. Three primary benefits of 2G networks over their predecessors were that phone conversations were digitally encrypted; 2G systems were significantly more efficient on the spectrum allowing for far greater mobile phone penetration levels; and 2G introduced data services for mobile, starting with SMS text messages.

2G technologies enabled the various mobile phone networks to provide the services such as text messages, picture messages, and MMS (multimedia messages). All text messages sent over 2G are digitally encrypted, allowing for the transfer of data in such a way that only the intended receiver can receive and read it.

2G technologies can be divided into time division multiple access (TDMA)-based and code division multiple access (CDMA)-based standards depending on the type of multiplexing used.

GSM (TDMA-based), originally from Europe but used in most of the world outside North America. Today accounts for over 80% of all subscribers around the world. Over 60 GSM operators are also using CDMA2000 in the 450 MHz frequency band (CDMA450).

IS-95 a.k.a. cdmaOne (CDMA-based, commonly referred as simply CDMA in the US), used in the Americas and parts of Asia. Today accounts for about 17% of all subscribers globally. Over a dozen CDMA operators have migrated to GSM including operators in Mexico, India, and Australia.

PDC also known as JDC (Japanese Digital Cellular) (TDMA-based), used exclusively in Japan
iDEN (TDMA-based), proprietary network used by Nextel in the United States and Telus Mobility in Canada.

IS-136 a.k.a. D-AMPS (TDMA-based, commonly referred as simply 'TDMA' in the US), was once prevalent in the Americas but most have migrated to GSM.

2G services are frequently referred as Personal Communications Service, or PCS, in the United States

2G started in 1991 with a speed for data transmission 9.6 kbit/s. In 1999, in the GSM standard is incorporated, the standard GPRS (considered as intermediate generation - 2.5G), which provides mobile Internet with greater speed.

Capacity

Using digital signals between the handsets and the towers increases system capacity in two key ways:

Digital voice data can be compressed and multiplexed much more effectively than analog voice encodings through the use of various codecs, allowing more calls to be transmitted in same amount of radio bandwidth.

The digital systems were designed to emit less radio power from the handsets. This meant that cells had to be smaller, so more cells had to be placed in the same amount of space. This was possible because cell towers and related equipment had become less expensive.

Data Transmission Capacity:

With GPRS (General Packet Radio Service), you have a theoretical transfer speed of max. 50 kbit/s (40 kbit/s in practice).

With EDGE (Enhanced Data Rates for GSM Evolution), you have a theoretical transfer speed of max. 1 Mbit/s (500 kbit/s in practice).

In less populous areas, the weaker digital signal transmitted by a cellular phone may not be sufficient to reach a cell tower. This tends to be a particular problem on 2G systems deployed on higher frequencies, but is mostly not a problem on 2G systems deployed on lower frequencies. National regulations differ greatly among countries which dictate where 2G can be deployed.

As distance increases, analog reception degrades gradually, but digital reception abruptly transitions from clear reception to no reception. This can be both an advantage and a disadvantage. Under good conditions, digital will sound better. Under slightly worse conditions, analog will experience static, while digital has occasional dropouts. As conditions worsen, though, digital will start to completely fail, by dropping calls or being unintelligible, while analog slowly gets worse, generally holding a call longer and allowing at least some of the audio transmitted to be understood.

Digital calls tend to be free of static and background noise, although the lossy compression used reduces audio quality, meaning that the range of call soundis reduced. Talking on a digital cell phone, a caller hears less of the tonality of someone's voice.

1.1.3 Third generation

The International Telecommunications Union (ITU) defined the third generation (3G) of mobile telephony standards IMT-2000 to facilitate growth, increase bandwidth, and support more diverse applications. For example, GSM could deliver not only voice, but also circuit-switched data at speeds up to 14.4 Kbps. But to support mobile multimedia applications, 3G had to deliver packet-switched data with better spectral efficiency, at far greater speeds. 3G finds application in wireless voice telephony, mobile Internet access, fixed wireless Internet access, video calls and mobile TV. The first 3G networks were introduced in 1998.

Data rates ITU has not provided a clear definition of the data rate that users can expect from 3G equipment or providers. It is expected that IMT-2000 will provide higher transmission rates: a minimum data rate of 2 Mbit/s for stationary or walking users, and 384 kbit/s in a moving vehicle. In market implementation, 3G downlink data speeds defined by telecom service providers vary depending on the underlying technology deployed; up to 384kbit/s for WCDMA, up to 7.2Mbit/sec for HSPA and a theoretical maximum of 21.6 Mbit/s for HSPA+.

The bandwidth and location information available to 3G devices gives rise to applications not previously available to mobile phone users. Some of the applications are Global Positioning System (GPS),Location-based services, Mobile TV, Telemedicine, Video Conferencing, Video on demand

1.1.4 Fourth generation

4G, short for fourth generation, is the fourth generation of mobile telecommunications technology, succeeding 3G. 4G (short for 4th Generation Communication Systems) represents the future of mobile communications in the longer term. The 4G architecture will build upon 3G. Certain components such as the circuit-switching elements are removed and Wireless LAN connectivity is added.

Carriers that use orthogonal frequency-division multiplexing (OFDM) instead of time division multiple access (TDMA) or code division multiple access (CDMA) are increasingly marketing their services as being 4G, even when their data speeds are not as fast as the

International Telecommunication Union (ITU) specifies. 4G will feature a scalable, flexible, efficient, autonomous, secure and feature-rich backbone to support a multitude of existing and new services and to interface with many different types of networks.

It will offer fully converged services (voice, data, and multimedia) at data rates of up to 100 Mbps and ubiquitous mobile access to a vast array of user devices autonomous networks.

Data rates up to 10 Gbps over the air.Latency in the order of 1ms.Enable Internetof Things (IoT) devices to run on battery for up to ten years.

If the latency is longer, users feel disturbed, unable to enjoy the seamless service. Tactile Internet, one of the most noted core features of 5G mobile communication, can support a low-latency mobile communication service capable of delivering tactile information in time. This kind of service requires extreme low latency to properly respond to users' requests. According to if tactile (the most latency-sensitive sense of all the five senses of human) information is to be delivered through a mobile communication system, the tolerable latency must be less than 1 ms to prevent users from experiencing any delay or lag.

Otherwise, users would suffer from discomfort, feeling so-called "cyber sickness". To avoid this cyber sickness, user-oriented service scenarios and relevant technologies must be secured so that, based on them, a mobile communication system with extreme low latency can be developed.

In addition to its No. 1 goal, achievement of lower end-to-end latency, 5G mobile communication systems have another goal, improvement of user experienced data rates. ITU-R WP 5D's 5D/TEMP/390-E defines them as follows:

Peak data rate: Peak data rate refers to the maximum achievable data rate per user. Future IMT systems should provide very high peak data rate capability that leads to high network capacity enabling new differentiated services and enriching the end user experience.

User experienced data rate: User experienced data rate is defined as the minimum data rate per user that should be achievable anytime anywhere. Future IMT systems should have the capability to provide anytime, anywhere [gigabit] data rate experience to mobile users. Also, Future IMT systems should provide an [“edgeless”] experience to the mobile users unlike the existing systems where the user experience is limited by the cell edge performance.

1.2 Fifth Generation communication technology

5G (5th generation mobile networks or 5th generation wireless systems) denotes the next major phase of mobile telecommunications standards beyond the current4G/IMT-Advanced standards. 5G has Internet connection speeds beyond what the current 4G can offer.

The Next Generation Mobile Networks Alliance defines the following requirements for 5G networks:

- Data rates of tens of megabits per second should be supported for tens of thousands of users
- 1 gigabit per second to be offered simultaneously to many workers on the same office floor
- Several hundreds of thousands of simultaneous connections to be supported for massive sensor deployments
- Spectral efficiency should be significantly enhanced compared to 4G
- Coverage should be improved
- Signalling efficiency should be enhanced
- Latency should be reduced significantly compared to LTE

1.2.1 Advantages of 5G communication system

- It could make better revenue for current global operators as well as interoperability will become more feasible.
- Improved and innovative data coding and modulation techniques, which includes filter bank multi carrier way in schemes.
- For wireless access and back haul use of millimeter wave frequencies is very useful.
- With the support of different conduction points with related coverage and surrounding the option of a supple usage of resources for up link and down link transmission in each cell is achieved by superior intrusion and mobility management.
- To make 5G practical for all sorts of radio access technologies there should be a common platform unique for all the technologies.
- Lower battery consumption.

- Lower outage probability.
- Better coverage and high data rates available at cell edge.
- Multiple concurrent data transfer paths.
- Possible to1Gbps and higher data rate in mobility.
- More secure; better cognitive radio/SDR Security.
- Higher system level spectral efficiency.
- World Wide Wireless Web (WWWW), wireless-based web applications that include full multimedia capability beyond 4G speeds.
- More applications combined with Artificial Intelligent (AI) as human life will be surrounded by artificial sensors which could be communicating with mobile phones.
- Not harmful to human health.
- Cheaper traffic fees due to low infrastructure deployment costs.
- Smart beam antenna systems.

1.2.2 Disadvantages of 5G communication system

Though, 5G technology is researched and conceptualized to solve all radio signal problems and hardship of mobile world, but because of some security reason and lack of technological advancement in most of the geographic regions, it has following shortcomings –

Technology is still under process and research on its viability is going on.
The speed, this technology is claiming seems difficult to achieve (in future, it might be) because of the incompetent technological support in most parts of the world.

Many of the old devices would not be competent to 5G, hence, all of them need to be replaced with new one — expensive deal.Developing infrastructure needs high cost.
Security and privacy issue yet to be solved.

1.3 Conclusion

The current status of the 5G technology for cellular systems is very much in the early development stages. Very many companies are looking into the technologies that could be used to become part of the system. In addition to this a number of universities have set up 5G research units focussed on developing the technologies for 5G

In addition to this the standards bodies, particularly 3GPP are aware of the development but are not actively planning the 5G systems yet.

Many of the technologies to be used for 5G will start to appear in the systems used for 4G and then as the new 5G cellular system starts to formulate in a more concrete manner, they will be incorporated into the new 5G cellular system.

The major issue with 5G technology is that there is such an enormously wide variation in the requirements: superfast downloads to small data requirements for IoT than any one system will not be able to meet these needs. Accordingly a layer approach is likely to be adopted. As one commentator stated: 5G is not just a mobile technology. It is ubiquitous access to high & low data rate services.

CHAPTER 2

TECHNOLOGIES OF 5TH GENERATION COMMUNICATION SYSTEM

2.1 Massive Multiple Input Multiple Output

Wireless communications is one of the most successful technologies in modern years, given that an exponential growth rate in wireless traffic has been sustained for over a century (known as Cooper's law). This trend will certainly continue driven by new innovative applications; for example, augmented reality and internet-of-things.

Multiple-antenna (MIMO) technology is becoming mature for wireless communications and has been incorporated into wireless broadband standards like LTE and Wi-Fi. Basically, the more antennas the transmitter/receiver is equipped with, the more the possible signal paths and the better the performance in terms of data rate and link reliability. The price to pay is increased complexity of the hardware (number of RF amplifier frontends) and the complexity and energy consumption of the signal processing at both ends.

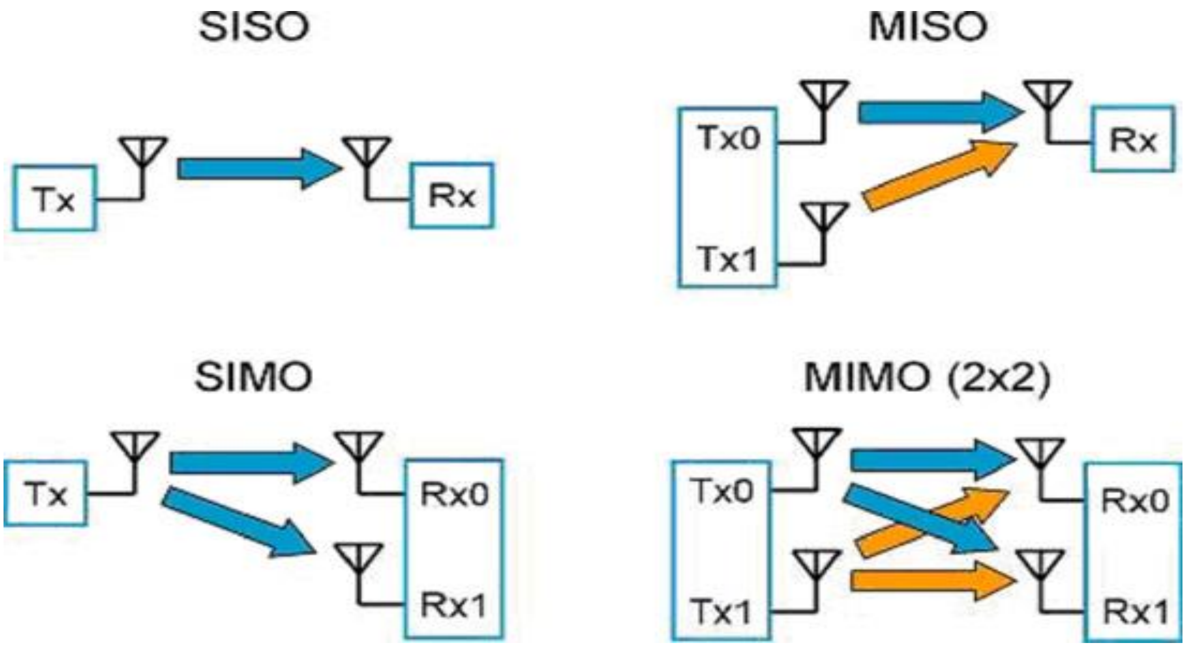


Fig2.1 Comparison among SISO, SIMO, MISO and MIMO

Massive MIMO (also known as **Large-Scale Antenna Systems**, **Very Large MIMO**, **Hyper MIMO**, **Full-Dimension MIMO** and**ARGOS**) makes a clean break with current practice through the use of a very large number of service antennas (e.g., hundreds or thousands) that are operated fully coherently and adaptively. Extra antennas help by focusing the transmission and reception of signal energy into ever-smaller regions of space. This brings huge improvements in throughput and energy efficiency, in particularly when combined with simultaneous scheduling of a large number of user terminals (e.g., tens or hundreds). Massive MIMO was originally envisioned for time division duplex (TDD) operation, but can potentially be applied also in frequency division duplex (FDD) operation. Other benefits of massive MIMO include the extensive use of inexpensive low-power components, reduced latency, simplification of the media access control (MAC) layer, and robustness to interference and intentional jamming. The anticipated throughput depends on the propagation environment providing asymptotically orthogonal channels to the terminals, and experiments have so far not disclosed any limitations in this regard. While massive MIMO renders many traditional research problems irrelevant, it uncovers entirely new problems that urgently need attention; for example, the challenge of making many low-cost low-precision components work effectively together, the need for efficient acquisition scheme for channel state information, resource allocation for newly-joined terminals, the exploitation of extra degrees of freedom provided by an excess of service antennas, reducing internal power consumption to achieve total energy efficiency reductions, and finding new deployment scenarios.

The canonical Massive MIMO system operates in time division duplex (TDD) mode, where the uplink and downlink transmissions take place in the same frequency resource but are separated in time [2]. The physical propagation channels are reciprocal—meaning that the channel responses are the same in both directions—which can be utilized in TDD operation. In particular, Massive MIMO systems exploit the reciprocity to estimate the channel responses on the uplink and then use the acquired channel state information (CSI) for both uplink receive combining and downlink transmit precoding of payload data. Since the transceiver hardware is generally not reciprocal, calibration is needed to exploit the channel reciprocity in practice [2]. Fortunately, the uplink-downlink hardware mismatches only change by a few degrees over a one-hour period and can be mitigated by simple relative calibration methods, even without extra reference transceivers and by only relying on mutual coupling between antennas in the array. There are several good reasons to operate in TDD mode. Firstly, only the BS needs to know the channels to process the antennas coherently. Secondly, the uplink estimation overhead is proportional to the number of terminals, but independent of M thus making the protocol fully scalable with respect to the number of service antennas. Furthermore, basic estimation theory tells us that the estimation quality (per antenna) cannot be reduced by adding more antennas at the BS—in fact, the estimation quality improves with M if there is a known correlation structure between the channel responses over the array . Since fading makes the channel responses vary over time and frequency, the estimation and payload transmission must fit into a time/frequency block where the channels are approximately static. The dimensions of this block are essentially given by the coherence bandwidth B_c Hz and the coherence time T_C s, which fit $\tau = B_c \times T_C$transmission symbols [2]. Massive MIMO can be implemented either using single-carrier or multi-carrier modulation. We consider multi-carrier OFDM modulation here for simplicity, because the coherence interval has a neat interpretation: it spans a number of subcarriers over which the channel frequency response is constant, and a number of OFDM symbols over which the channel is constant.The channel coherency depends on the propagation environment, user mobility, and the carrier frequency.

2.1.1 LINEAR PROCESSING

The payload transmission in Massive MIMO is based on linear processing at the BS. In the uplink, the BS has M observations of the multiple access channel from the K terminals. The BS applies linear receive combining to discriminate the signal transmitted by each terminal from the interfering signals. The simplest choice is maximum ratio (MR) combining that uses the channel estimate of a terminal to maximize the strength of that terminal's signal, by adding the signal components coherently. This results in a signal amplification proportional to M, which is known as an array gain. Alternative choices are zero-forcing (ZF) combining, which suppresses inter-cell interference at the cost of reducing the array gain to $M - K + 1$, and minimum mean squared error (MMSE) combining that balances between amplifying signals and suppressing interference. The receive combining creates one effective scalar channel per terminal where the intended signal is amplified and/or the interference is suppressed. Any judicious receive combining will improve by adding more BS antennas, since there are more channel observations to utilize. The remaining interference is typically treated as extra additive noise, thus conventional single-user detection algorithms can be applied. Another benefit from the combining is that small-scale fading averages out over the array, in the sense that its variance decreases with M. This is known as channel hardening and is a consequence of the law of large numbers. Since the uplink and downlink channels are reciprocal in TDD systems, there is a strong connection between receive combining in the uplink and the transmit precoding in the downlink ,this is known as uplink-downlink duality. Linear precoding based on MR, ZF, or MMSE principles can be applied to focus each signal at its desired terminal (and possibly mitigate interference towards other terminals).

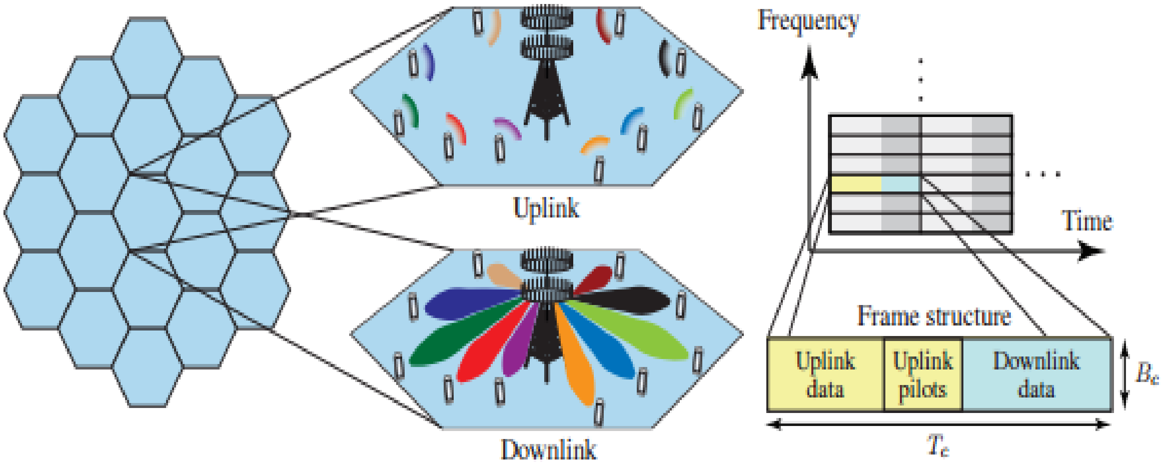


Fig2.2Illustration of the uplink and downlink in line-of-sight propagation, where each BS is equipped with M antennas and serves K terminals [3]

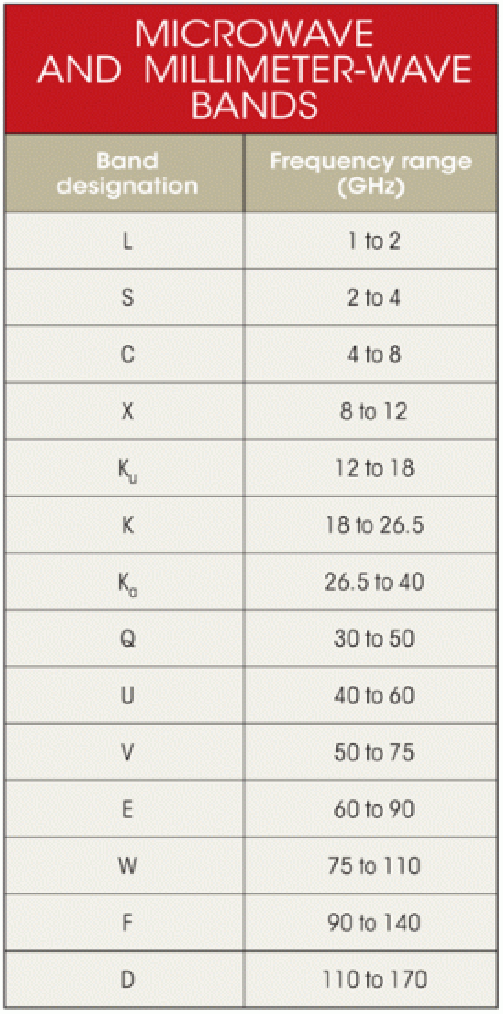
Many convenient closed-form expressions for the achievable uplink or downlink spectral efficiency (per cell) can be found in the literature.

While canonical Massive MIMO systems operate with single-antenna terminals, the technology also handles Nantenna terminals. In this case, K denotes the number of simultaneous data streams and describes the spectral efficiency per stream. These streams can be divided over anything from K/N to K terminals.

The channel response between a terminal and the BS can be represented by an M-dimensional vector. Since the K channel vectors are mutually non-orthogonal in general, advanced signal processing (e.g., dirty paper coding) is needed to suppress interference and achieve the sum capacity of the multi-user channel. Favorable propagation (FP) denotes an environment where the K users' channel vectors are mutually orthogonal (i.e., their inner products are zero). FP channels are ideal for multi-user transmission since the interference is removed by simple linear processing (i.e., MR and ZF) that utilizes the channel orthogonality [2].

An approximate form of favorable propagation is achieved in non-line-of-sight (non-LoS) environments with rich scattering, where each channel vector has independent stochastic entries with zero mean and identical distribution. Under these conditions, the inner products (normalized by M) go to zero as more antennas are added; this means that the channel vectors get closer and closer to orthogonal as M increases. The sufficient condition above is satisfied for Rayleigh fading channels, which are considered in the vast majority of works on Massive MIMO, but approximate favorable propagation is obtained in many other situations as well.

2.2 Millimeter Wave



MICROWAVE AND MILLIMETER-WAVE BANDS

Band designation	Frequency range (GHz)
L	1 to 2
S	2 to 4
C	4 to 8
X	8 to 12
K_u	12 to 18
K	18 to 26.5
K_a	26.5 to 40
Q	30 to 50
U	40 to 60
V	50 to 75
E	60 to 90
W	75 to 110
F	90 to 140
D	110 to 170

Fig 2.3 Microwave and Millimeter wave bands [2]

Millimeter wave, which is also known as extremely high frequency (EHF) or very high frequency (VHF) by the International Telecommunications Union (ITU), can be used for high-speed wireless broadband communications. Millimeter wave is an undeveloped band of spectrum that can be used in a broad range of products and services like high speed, point-to-point wireless local area networks (WLANs) and broadband access. In telecommunications, millimeter wave is used for a variety of services on mobile and wireless networks, as it allows for higher data rates up to 10 Gigabits per second(Gbps).

Millimeter waves have short wavelengths that range from 10 millimeters to 1 millimeter; they have high atmospheric attenuation and are absorbed by gases in the atmosphere, which reduces the range and strength of the waves. Rain and humidity can impact performance and reduce signal strength, a condition known rain fade. Due to its short range of about a kilometer, millimeter wave travels by line of sight, so its high-frequency wavelengths can be blocked by physical objects like buildings and trees.

Millimeter waves occupy the frequency spectrum from 30 GHz to 300 GHz. They're found in the spectrum between microwaves (1 GHz to 30 GHz) and infrared (IR) waves, which is sometimes known as extremely high frequency (EHF). The wavelength (λ) is in the 1-mm to 10-mm range. At one time this part of the spectrum was essentially unused simply because few if any electronic components could generate or receive millimeter waves.

All that has changed in the past decade or so. Millimeter waves are now practical and affordable, and they're finding all sorts of new uses. Best of all, they take the pressure off the lower frequencies and truly expand wireless communications into the outer limits of radio technology . If we go any higher in frequency, we will be using light.

Millimeter waves open up more spectrum. Today, the spectrum from dc through microwave (30 GHz) is just about used up. Government agencies worldwide have allocated all of the "good" spectrum. There are spectrum shortages and conflicts. The expansion of cellular services with 4G technologies like LTE depends on the availability of the right sort of spectrum. The problem is that there isn't enough of it to go around.

As a result, spectrum is like prime real estate—it's expensive. And the expression "location, location, location" is apt for spectrum. Millimeter waves partially solve the problem by providing more room for expansion. You can take all of the useful spectrum we now use from dc to 30 GHz and drop it into the lower end of the millimeter-wave region and still have 240 GHz left over.

Millimeter waves also permit high digital data rates. Wireless data rates in microwave frequencies and below are now limited to about 1 Gbps. In the millimeter-wave range, data rates can reach 10 Gbps and more.

The bad news is that while this spectrum gives us some expansion room, it isn't useful for all types of wireless applications. It has its limitations. Overcoming those shortcomings has been the challenge of making millimeter waves practical and affordable. That time has come.

One of the key limitations of millimeter waves is the limited range. The laws of physics say that the shorter the wavelength, the shorter the transmission range for a given power. At reasonable power levels, this limitation restrains the range to less than 10 meters in many cases.

The free space loss in dB is calculated with:

$L = 92.4 + 20\log(f) + 20\log(R)$

R is the line-of-sight (LOS) distance between transmit and receive antennas in kilometers, and f is the frequency in gigahertz. For example, the loss at 10 meters at 60 GHz is:

$L = 92.4 + 35.6 – 40 = 88$ dB

Designers can overcome this loss with good receiver sensitivity, high transmit power, and high antenna gains.

Video signals demand the greatest bandwidth and, accordingly, a higher data rate. Speeds of many gigabits per second are needed to transmit 1080p high definition (HD) video. That data rate can be reduced if video compression techniques are used prior to transmission. Then, data rates of several hundred meagbits per second can get the job done, but usually at the expense of the video quality.

Compression techniques invariably diminish the quality to allow available wireless standards like Wi-Fi 802.11n to be used. Standards like 802.11ac that use greater bandwidth in the 5-GHz band are now available to achieve gigabit data rates. Millimeter-wave technologies make gigabit rates commonplace and relatively easy to achieve, making uncompressed video a reality.

LTE and 4G cellular technology rollouts are limited by spectrum availability. LTE uses lots of bandwidth, and carriers only have so much spectrum. The cost of buying new spectrum is high, and the amount of spectrum is limited. Carriers are resorting to all sorts of maneuvers to get the spectrum to build LTE capacity and revenue.

One solution is to go to a TD-LTE (time division duplex) format that uses only half the spectrum of FDD-LTE (frequency division duplex). That doesn't seem to be on the roadmap for many carriers, however. Small cells are a more popular solution. Microcells, picocells, and femtocells are limited-range basestations that are being deployed to fill in the gaps in macro basestation coverage. With limited range, these small cells will adopt frequency reuse techniques to provide more efficient use of the spectrum available.

The small-cell movement, also called heterogeneous networks or HetNets, may eventually become the fifth generation (5G) of cellular systems. But that's not all. The small cells may use the millimeter-wave bands to provide that precious coveted spectrum needed for expansion.

Highly directional antennas with automatic positioning and beamforming can make millimeter-wave frequencies work for cellular phones that demand great link reliability. Watch for more developments in this area.

While research has produced transistors that function beyond 100 GHz, their usefulness dies around 300 GHz or so because of excessive transit time through the device. Strangely enough, there are semiconductor devices that do work in the optical spectrum above the terahertz zone.

Infrared extends from roughly 700 nm to 2000 nm or 430 THz to 150 THz. Visible light extends from about 400 nm (violet) to 700 nm (red) or about 430 THz to 750 THz. Ultraviolet light is beyond 740 THz. Lasers and LEDs can generate these waves and photodiodes can detect them, but they don't work at the lower terahertz frequencies. There is a dead zone from roughly 300 GHz to 100 THz where few if any practical devices exist.

2.3 Cognitive Radio

A cognitive radio (CR) is an intelligent radio that can be programmed and configured dynamically. Its transceiver is designed to use the best wireless channels in its vicinity. Such a radio automatically detects available channels in wireless spectrum, then accordingly changes its transmission or reception parameters to allow more concurrent wireless communications in a given spectrum band at one location. This process is a form of dynamic spectrum management.

The point in which wireless personal digital assistants (PDAs) and the related networks are sufficiently computationally intelligent about radio resources and related computer-to-computer communications to detect user communications needs as a function of use context, and to provide radio resources and wireless services most appropriate to those needs.

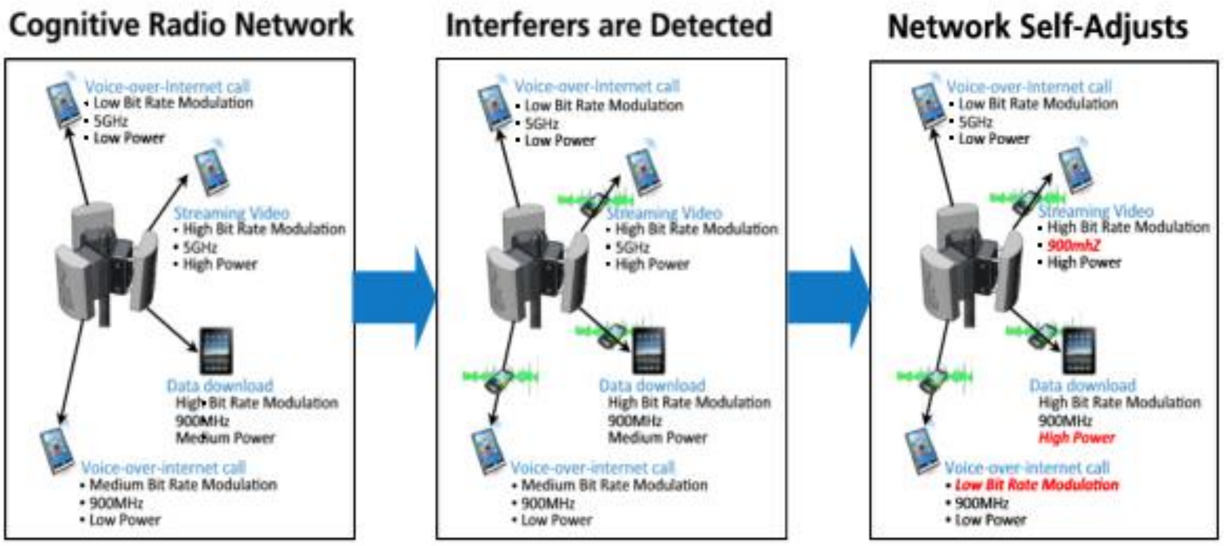


Fig 2.4 Working of a Cognitive Radio [17]

Cognitive radio is considered as a goal towards which a software-defined radio platform should evolve: a fully reconfigurable wireless transceiver which automatically adapts its communication parameters to network and user demands.

Traditional regulatory structures have been built for an analog model and are not optimized for cognitive radio. Regulatory bodies in the world as well as different independent measurement campaigns found that most radio frequency spectrum was inefficiently utilized. Cellular network bands are overloaded in most parts of the world, but other frequency bands (such as military, amateur radio and paging frequencies) are insufficiently utilized. Independent studies performed in some countries confirmed that observation, and concluded that spectrum utilization depends on time and place. Moreover, fixed spectrum allocation prevents rarely used frequencies (those assigned to specific services) from being used, even when any unlicensed users would not cause noticeable interference to the assigned service. Regulatory bodies in the world have been considering whether to allow unlicensed users in licensed bands if they would not cause any interference to licensed users. These initiatives have focused cognitive-radio research on dynamic spectrum access.

Although cognitive radio was initially thought of as a software-defined radio extension (full cognitive radio), most research work focuses on spectrum-sensing cognitive radio (particularly in the TV bands). The chief problem in spectrum-sensing cognitive radio is designing high-quality spectrum-sensing devices and algorithms for exchanging spectrum-sensing data between nodes. It has been shown that a simple energy detector cannot guarantee the accurate detection of signal presence, calling for more sophisticated spectrum sensing techniques and requiring information about spectrum sensing to be regularly exchanged between nodes. Increasing the number of cooperating sensing nodes decreases the probability of false detection.

2.3.1 Functions of a Cognitive Radio

Spectrum sensing is active spectrum awareness process where cognitive radio monitors its radio environment and geographical surroundings, detect usage statistics of other primary and secondary users and determine possible spectrum space holes. Spectrum sensing can be done by one cognitive radio, by multiple cognitive radio terminals or by independent sensing network exchanging information in a cooperative way which improves overall accuracy.

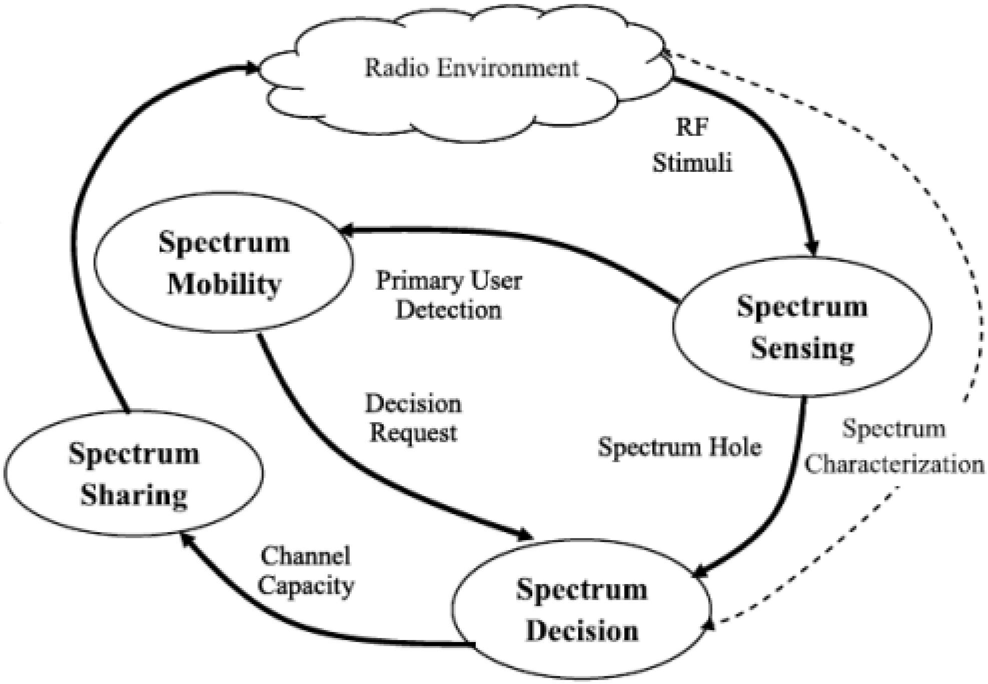


Fig 2.5 Cognitive Cycle of a CR

Spectrum decision: Based on spectrum sensing information cognitive radio selects when to start its operation, operating frequency and its corresponding technical parameters. Cognitive radio primary objective is to transfer as much as possible information and to satisfy required quality of service, without causing excessive interference to the primary users. Additionally, cognitive radio may use data from regulatory database and policy database in order to improve its operation and outage statistics.

Spectrum sharing: Since there is number of secondary users participating in usage of available spectrum holes, cognitive radio has to achieve balance between its self-goal of transferring information in efficient way and altruistic goal to share the available resources with other cognitive and non-cognitive users. This is done with policy rules determining cognitive radio behaviour in radio environment.

Spectrum mobility: If primary user starts to operate, cognitive radio has to stop its operation or to vacate currently used radio spectrum and change radio frequency. In order to avoid interference to primary licensed user this function has to be performed in real time, therefore cognitive radio has to constantly investigate possible alternative spectrum holes.

Researchers throughout the World are trying to find out the best methods to develop a radio communications system that would be able to fulfil the requirements for a Cognitive radio system. It has been seen that Cognitive radio is the emerging spectrum sharing technology and can be the best option for future generation wireless networks because of present spectrum crisis and uneven use of spectrum. A fuzzy logic based spectrum management technique is proposed here which will help to take wise decision regarding spectrum sharing in cognitive networks. The method considers four input parameters including availability of spectrum and thus is a practicable solution for spectrum sharing. The simulation software programs for the proposed system are neither complex nor consume much time to respond. Hence, it can be easily embedded into application programs and can be implemented in real systems.

2.4 Conclusion

By accounting for the majority of needs, the following set of 5G requirements is gaining industry acceptance.1-10Gbps connections to end points in the field (i.e. not theoretical maximum).1 millisecond end-to-end round trip delay – latency.1000x bandwidth per unit area.10-100x number of connected devices.90% reduction in network energy usage. Up to ten year battery life for low power, machine-type devices.

One of the key issues with the 5G requirements is that there are many different interested parties involved, each wanting their own needs to be met by the new 5G wireless system. This leads to the fact that not all the requirements form a coherent list. No one technology is going to be able to meet all the needs together.

As a result of these widely varying requirements for 5G, many anticipate that the new wireless system will be a umbrella that enables a number of different radio access networks to operate together, each meeting a set of needs. As very high data download and ultra low latency requirements do not easily sit with low data rate and long battery life times, it is likely that different radio access networks will be needed for each of these requirements.

Accordingly it is likely that various combinations of a subset of the overall list of requirements will be supported when and where it matters for the 5G wireless system.

CHAPTER-3

FADING

3.1 INTRODUCTION TO FADING

In wireless communications, fading is deviation of the attenuation affecting a signal over certain propagation media. The fading may vary with time, geographical position or radio frequency, and is often modelled as a random process. A fading channel is a communication channel that experiences fading [3]. In wireless systems, fading may either be due to multipath propagation, referred to as multipath induced fading, or due to shadowing from obstacles affecting the wave propagation, sometimes referred to as shadow fading.

A common example of deep fade is the experience of stopping at a traffic light and hearing an FM broadcast degenerate into static, while the signal is re-acquired if the vehicle moves only a fraction of a meter. The loss of the broadcast is caused by the vehicle stopping at a point where the signal experienced severe destructive interference. Cellular phones can also exhibit similar momentary fades.

Fading channel models are often used to model the effects of electromagnetic transmission of information over the air in cellular networks and broadcast communication. Fading channel models are also used in underwater acoustic communications to model the distortion caused by the water [13].

3.2 TYPES OF FADING

3.2.1 SLOW FADING

Slow fading arises when the coherence time of the channel is large relative to the delay requirement of the application. In this regime, the amplitude and phase change imposed by the channel can be considered roughly constant over the period of use. Slow fading can be caused by events such as shadowing where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver [4]. The received power change caused by shadowing is often modelled using a log-normal distribution with a standard deviation according to the log-distance path loss model. In a slow-fading channel, it is not possible to use time diversity because the transmitter sees only a single realization of the channel within its delay constraint.

3.2.2 FAST FADING

Fast fading occurs when the coherence time of the channel is small relative to the delay requirement of the application. In this case, the amplitude and phase change imposed by the channel varies considerably over the period of use. In a fast-fading channel, the transmitter may take advantage of the variations in the channel conditions using time diversity to help increase robustness of the communication to a temporary deep fade. Although a deep fade may temporarily erase some of the information transmitted, use of an error-correcting code coupled with successfully transmitted bits during other time instances (interleaving) can allow for the erased bits to be recovered.

3.2.3 BLOCK FADING

Block fading is where the fading process is approximately constant for a number of symbol intervals. A channel can be 'doubly block-fading' when it is block fading in both the time and frequency domains.

3.2.4 SELECTIVE FADING

Selective fading or frequency selective fading is a radio propagation anomaly caused by partial cancellation of a radio signal by itself — the signal arrives at the receiver by two, and at least one of the paths is changing (lengthening or shortening). This typically happens in the early evening or early morning as the various layers in the ionosphere move, separate, and combine. The two paths can both be sky wave or one be ground wave.

Selective fading manifests as a slow, cyclic disturbance, the cancellation effect, or "null", is deepest at one particular frequency, which changes constantly, sweeping through the received audio.

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

- In flat fading, the coherence bandwidth of the channel is larger than the bandwidth of the signal. Therefore, all frequency components of the signal will experience the same magnitude of fading.
- In frequency-selective fading, the coherence bandwidth of the channel is smaller than the bandwidth of the signal. Different frequency components of the signal therefore experience uncorrelated fading.

3.3 FADING MODELS

3.3.1 RAYLEIGH FADING MODEL

Rayleigh fading is a statistical model for the effect of a propagation environment on a radio signal, such as that used by wireless devices [15].

Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium (also called a communications channel) will vary randomly, or fade, according to a Rayleigh distribution — the radial component of the sum of two uncorrelated Gaussian random variables.

Rayleigh fading is viewed as a reasonable model for tropospheric and ionospheric signal propagation as well as the effect of heavily built-up urban environments on radio signals. Rayleigh fading is most applicable when there is no dominant propagation along a line of sight between the transmitter and receiver. If there is a dominant line of sight, Rician fading may be more applicable [14].

For any two Gaussian random variables X and Y , both with mean zero and equal variance σ^2 ,it can be shown that Z=$\sqrt{x^2+y^2}$ is Rayleigh-distributed and Z^2 is exponentially distributed.

If we assume a variance of σ^2 for both in-phase and quadrature components then the signal envelope $z(t) = |r(t)| = \sqrt{r_I^2(t) + r_Q^2(t)}$ is Rayleigh distributed with distribution

$$p_Z(z) = \frac{2z}{P_r}\exp[-z^2/P_r] = \frac{z}{\sigma^2}\exp[-z^2/(2\sigma^2)], \quad x \geq 0,$$

where $P_r = \sum_n E[\alpha_n^2] = 2\sigma^2$ is the average received signal power of the signal, i.e. the received power based on path loss and shadowing alone.[14]

We obtain the power distribution by making the change of variables $z^2(t) + |r(t)|^2$to obtain

$$p_{Z^2}(x) = \frac{1}{P_r}e^{-x/P_r} = \frac{1}{2\sigma^2}e^{-x/(2\sigma^2)}, \quad x \geq 0.$$

3.3.2 RICIAN FADING MODEL

Rician fading is a stochastic model for radio propagation anomaly caused by partial cancellation of a radio signal by itself — the signal arrives at the receiver by several different paths (hence exhibiting multipath interference), and at least one of the paths is changing (lengthening or shortening). Rician fading occurs when one of the paths, typically a line of sight signal, is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician distribution.

In this case the received signal equals the superposition of a complex Gaussian component and a LOS component. The signal envelope in this case can be shown to have a Riciandistribution , given by

$$p_Z(z) = \frac{z}{\sigma^2}\exp\left[\frac{-(z^2+s^2)}{2\sigma^2}\right] I_0\left(\frac{zs}{\sigma^2}\right), \quad x \geq 0,$$

$2\sigma^2 = \sum_{n,n\neq 0} E[\alpha_n^2]$where is the average power in the non-LOS multipath components and $s^2 = \alpha_0^2$is the power in the LOScomponent. The function I0 is the modified Bessel function of 0th order.

The average received power in the Rician fading is given by

$$P_r = \int_0^\infty z^2 p_Z(z)dx = s^2 + 2\sigma^2.$$

The Rician distribution is often described in terms of a fading parameter *K*, defined by

$$K = \frac{s^2}{2\sigma^2}.$$

Thus, *K* is the ratio of the power in the LOS component to the power in the other (non-LOS) multipath components. For *K* = 0 we have Rayleigh fading, and for *K = 1* we have no fading, i.e. a channel with no multipath and only a LOS component. The fading parameter *K* is therefore a measure of the severity of the fading: a small *K* implies severe fading, a large *K* implies more mild fading. Making the substitution $s^2 = KP/(K+1)$ and $2\sigma^2 = P/(K+1)$ we can write the Rician distribution in terms of *K* as

$$p_Z(z) = \frac{2z(K+1)}{P_r} \exp\left[-K - \frac{(K+1)z^2}{P_r}\right] I_0\left(2z\sqrt{\frac{K(K+1)}{P_r}}\right), \quad z \geq 0.$$

3.3.3 NAKAGAMI FADING MODEL

The Nakagami distribution or the Nakagami-m distribution is a probability distribution related to the distribution. Since some experimental data does not fit well into either of these distributions. Thus, a more general fading distribution was developed whose parameters can be adjusted to fit a variety of empirical measurements. This distribution is called the Nakagami fading distribution, and is given by

$$p_Z(z) = \frac{2m^m x^{2m-1}}{\Gamma(m) P_r^m} \exp\left[\frac{-mz^2}{P_r}\right], \quad m \geq .5,$$

wherePr is the average received power. The Nakagami distribution is parameterized by Pr and the fading parameter m. For m = 1 the distribution reduces to Rayleigh fading. For m = (K+1)2/(2K+1)the distribution is approximately Rician fading with parameter K. For m = 1 we get no fading. Thus, the Nakagami distribution can model Rayleigh and Rician distributions, as well as more general ones. Note that some empirical measurements support values of the m parameter less than one, in which case the Nakagami fading causes more severe performance degradation than Rayleigh fading [1]. The power distribution for Nakagami fading, obtained by a change of variables, is given by

$$p_{Z^2}(x) = \left(\frac{m}{P_r}\right)^m \frac{x^{m-1}}{\Gamma(m)} \exp\left(\frac{-mx}{P_r}\right).$$

3.4 Conclusion

The Rayleigh fading model is normally viewed as a suitable approach to take when analysing and prediction radio wave propagation performance for areas such as cellular communications in a well built up urban environment where there are many reflections from buildings, etc.HF ionospheric radio wave propagation where reflections (or more exactly refractions) occur at many points within the ionosphere is also another area where Rayleigh fading model applies well. It is also appropriate to use the Rayleigh fading model for tropospheric radio propagation because, again there are many reflection points and the signal may follow a variety of different paths.

When there is a dominant stationary (nonfading) signal component present, such as a line-of sight propagation path, the small-scale fading envelope distribution is Ricean. In such a situation, random multipath components arriving at different angles are superimposed on a stationary dominant signal. At the output of an envelope detector, this has the effect of adding a dc component to the random multipath.

Just as for the case of detection of a sine wave in thermal noise, the effect of a dominant signal arriving with many weaker multipath signals gives rise to the Rician distribution.

As the dominant signal becomes weaker, the composite signal resembles a noise signal which has an envelope that is Rayleigh.

The Rician and the Nakagami model behave approximately equivalently near their mean value.

This observation has been used in many recent papers to advocate the Nakagami model as an approximation for situations where a Rician model would be more appropriate. While this may be accurate for the main body of the probability density, it becomes highly inaccurate for the tails. As bit errors or outages mainly occur during deep fades, these performance measures are mainly determined by the tail of the probability density function

CHAPTER-4

GENERALIZED K-FADING

4.1 INTRODUCTION

The received signal over a wireless channel is usually characterized by the joint effect of two independent random processes such as small scale fading due to the arrival of multiple, randomly delayed, refracted, reflected and scattered signal components at the receiver and large scale fading due to the shadowing from various obstacles in the propagation path. Therefore, it is very useful for various wireless system designers to have a generic statistical model that encompasses both of these random processes. Several fading models like Rayleigh, Rician and Nakagami have been proposed to model the short-term fading channel [2].

In addition to the multipath fading in the wireless environment, the quality of signal is also affected due to the shadowing from various obstacles in the propagation path.

The Nakagami-m and Rayleigh-lognormal (R-L) are well known composite statistical distribution to model the multipath fading and shadowing [5]. As these distributions do not have any closed-form Mathematical solution , therefore it is difficult to use it widely.

However, they have been approximated by the Generalized-K distribution and K-distribution.

In this, we have proposed the marginal moment generating function (MMGF) based channel

Capacity analysis over the Generalized-K fading environment with L-branch MRC diversity.[6] The main contribution consists of the evaluation the MMGF and the derived mathematical expression for MMGF is used to obtain a closed-form expression for the channel capacity under optimal rate adaptation with constant transmit power (CORA) and channel inversion with fixed rate (CIFR). The derived results are generic and applicable to other type of fading.

However, the mathematical model for the channel capacity of a fading channel has a complex expression in terms of the channel variation with time and/or frequency and also depends upon the transmitter's and/or receiver's knowledge of the channel state information [7]. Various definitions of the channel capacity have been proposed on the basis of various channel state information, which rely on the employed power and rate adaptation policies as well as the outage probability [20].

In expressions derived, a novel closed-form mathematical expression for the outage performance, average bit-error probabilities of several modulation formats and channel capacity under four different adaptation transmission schemes for the digital communication systems operating over a composite fading channel modeled by a generalized-K distribution are derived [7]. For the computation of CORA we have evaluated approximate value by calculating limit at ($a \rightarrow 1$) and formula for CORA is valid only for the non-integer values of the distribution shaping parameters (k) and (m). If k and m are the integers then the formula for CORA fails.

In this report, the moment generating function (MGF) based approach has been proposed for the computation of the channel capacity only for CORA scheme by using the numerical techniques.

A MGF based approach is developed for the evaluation of channel capacity for several rate adaptations and transmit power schemes.

There has been proposed the marginal moment generating function (MMGF) based channel capacity analysis over the Generalized-K fading environment with L-branch MRC diversity [9]. The main contribution consists of the evaluation the MMGF and the derived mathematical expression for MMGF is used to obtain a closed-form expression for the channel capacity under optimal rate adaptation with constant transmit power (CORA) and channel inversion with fixed rate (CIFR) [8]. The derived results are generic and applicable to other type of fading.

4.2 GENERALIZED-K FADING CHANNEL MODEL

We have considered the L-branch maximal ratio combing (MRC) diversity receiver. The received baseband signal on ith branch can be written as:

$$r_i = s(t) X_i e^{j\phi_i} + n_i(t), \qquad i = 1, 2, \ldots\ldots\ldots\ldots, L$$

$$f_X(x) = \frac{4\, x^{Lm+k-1}}{\Gamma(mL)\Gamma(k)} \left(\frac{m}{\Omega}\right)^{\frac{k+mL}{2}} K_{k-mL}\left[2\left(\frac{m}{\Omega}\right)^{1/2} x\right], \qquad x \geq 0$$

where s(t) is the transmitted signal and $n_t(t)$ is the identically distributed white Gaussian noise with zero-mean. The$\emptyset_i$ is the uniformly distributed over the range [0, 2π) and Xi is the Generalized-K distributed signal envelop with the probability distribution function given by

where k and m are the distribution shaping parameters accounting for the shadowing and Nakagami-m fading associated with the channel. $K_v(.)$is the modified Bessel function of order v(.). $\Omega = \frac{E[X^2]}{k}$is the mean power and E[.] denotes expectation. The instantaneous signal-to-noise ratio (SNR) per received symbol at the output of diversity branch is:$\gamma = \frac{X^2 E_S}{N_0}$ where ES is the average symbol energy and N0 is the single-sided power spectral density of the additive white Gaussian noise (AWGN).

Assuming all the branches are identical and corresponding average SNR is given as:$\bar{\gamma} = \frac{k\Omega E_S}{N_0}$

By changing variables, the PDF of γ

$$f_\gamma(\gamma) = \frac{2\,(\gamma)^{(\alpha-1)/2}}{\Gamma(mL)\Gamma(k)} (\Xi)^{(\alpha+1)/2} K_\beta\left[2\sqrt{\Xi\gamma}\right] \qquad \gamma \geq 0$$

Where α= mL+ k -1, β = k + mL and Ξ= k m/$\bar{\gamma}$. The MMGF is one of the most important characteristics of the any distribution function because it helps in the bit-error-rate as well as channel capacity performance evaluation of the wireless communication systems.

4.2.1 MARGINAL MOMENT GENERATING FUNCTION

The channel capacity has been regarded as the fundamental information theoretic performance measure to predict the maximum information rate of a communication system. It is extensively used as the basic tool for the analysis and design of more efficient techniques to improve the spectral efficiency of the modern wireless communication systems and to gain insight into how to counteract the detrimental effects of the multipath fading propagation via opportunistic and adaptive communication methods [21].

The main reason for the analysis of spectral efficiency over fading channels is represented by the fact that most framework described in various literature make use of the so-called probability density function(PDF) based approach of the received SNR, which is a task that might be very cumbersome for system setups and often require to manage mathematical expressions [8]. It is also well known fact that the prior knowledge of the channel state information at the transmitter is exploited to improve the channel capacity such that in the low SNR regime, the maximum achievable data rate of the without fading channel might be much larger than fading channel [10]. The MGF and CF (characteristics function) based approach have extensively been used for analyzing the average bit-error-rate probability and outage probability [20].

The application of PDF based approach for computation of the channel capacity appear to be in evident counter tendency with recent advances on performance analysis of the digital communication over fading channels.

Several researchers have demonstrated the significance of using either MGF or CF–based approach for simplifying the analysis in most situation of interest for the computation of important performance parameters, whereas the application of PDF based approach seems impractical [11]. Recent advances in the performance analysis of digital communication systems in the fading environment has recognized the potential importance of the MGF or Laplace transforms as a powerful tools for simplifying the analysis of diversity communication systems. This led to a simple expression to average bit-error-rate and symbol-error-rate for wide variety of digital communication scheme on fading channels including multipath reception with correlated diversity [6].

The potential key for these developments was the transformation of conditional error-rate expressions into different equivalent forms in which the conditional variable appears only as an exponent [5].

MMGF is evaluated for L- branch MRC diversity and further, it is used for computation of the channel capacity. The MMGF is defined as

$$\hat{M}(s,a) = \int_{a}^{\infty} e^{-s\gamma} f_{\gamma}(\gamma) d\gamma$$

Further substituting $f_\gamma(\gamma)$, we get

$$\hat{M}(s,a) = \frac{1}{\Gamma(mL)\,\Gamma(k)\sin\pi\beta}\left(\sum_{p=0}^{\infty}\frac{2}{p!\Gamma(p-\beta+1)}(\Xi)^{\frac{\alpha-\beta+2p+1}{2}}(s)^{-\frac{(\alpha-\beta+2p+1)}{2}}\Gamma\left(\frac{\alpha-\beta+2p+1}{2},as\right)-\right.$$

$$\left.\sum_{p=0}^{\infty}\frac{1}{p!\Gamma(p+\beta+1)}(\Xi)^{\frac{\alpha+\beta+2p+1}{2}}(s)^{-\frac{(\alpha+\beta+2p+1)}{2}}\Gamma\left(\frac{\alpha+\beta+2p+1}{2},as\right)\right)$$

If we put lower limit a = 0 then MMGF is changes to MGF. The MGF function is one of most important characteristics of any distribution function because it helps in bit-error rate performance evaluation for various kind of modulation as well as channel capacity computation of the wireless communication systems. The MGF is defined as

$$M(s) = \int_0^\infty \exp(-s\gamma)\, f_\gamma(\gamma)\, d\gamma$$

By substituting further we get

$$M(s) = \frac{2(\Xi)^{(\alpha+1)/2}}{\Gamma(mL)\Gamma(k)} \int_0^\infty \exp(-s\gamma)\,(\gamma)^{(\alpha-1)/2} K_\beta\left[2\sqrt{\Xi\gamma}\right] d\gamma$$

4.3 Conclusion

In this section, we have proposed some alternative mathematical expressions for the computation of channel capacity relying on the knowledge of the MGF Mγ (.) of γ.

In the following section, we have presented closed-from expression for CORA and CCIFR schemes. It is difficult to obtain a closed-form expression for the channel capacity using MGF based approach for optimal simultaneous power and rate adaptation (COPRA) and the truncated channel inversion with fixed rate (CTCIFR) schemes. Therefore, COPRA and CTCIFR are computed using a MMGF based approach.

CHAPTER 5

MGF-BASED CHANNEL CAPACITY ANALYSIS

5.1 OPTIMAL RATE ADAPTATION WITH CONSTANT TRANSMIT POWER

When the transmitter power remains constant, usually as a result of channel state information (CSI) being available at receiver side, the channel capacity with optimal rate adaptation (CORA) in the terms of the MGF based approach can be expressed as

$$C_{ORA} = \frac{1}{\ln(2)} \int_0^{\infty} \frac{e^{-s}\left(1 - M(s)\right)}{s} ds$$

where$M(s)$ is MGF

Now from the equation underlying

$$M(s) = \frac{(\Xi/s)^{\frac{\alpha+1}{2}}}{\Gamma(mL)\Gamma(k)} G_{1\ \ 2}^{2\ \ 1}\left[\frac{\Xi}{s}\middle| \begin{matrix} (1-\alpha)/2 & \\ \beta/2 & -\beta/2 \end{matrix}\right]$$

Where G(.) is the Meijer's G function

We get

$$I_4 = -\frac{1}{\ln(2)} \int_0^{\infty} \frac{e^{-s} \frac{(\Xi/s)^{\frac{\alpha+1}{2}}}{\Gamma(mL)\Gamma(k)} G_{1\ \ 2}^{2\ \ 1}\left[\frac{\Xi}{s}\middle| \begin{matrix} (1-\alpha)/2 & \\ \beta/2 & -\beta/2 \end{matrix}\right]}{s} ds$$

And after doing some mathematical manipulations we get

$$C_{ORA} \approx -\frac{1}{\ln(2)}\frac{(\Xi)^{\frac{\alpha+1}{2}}}{\Gamma(mL)\Gamma(k)}G^{1\quad 3}_{3\quad 1}\left[\frac{1}{\Xi}\middle|\begin{matrix}1+(\alpha+1)/2 & 1-\beta/2 & 1+\beta/2\\ (\alpha+1)/2 & & \end{matrix}\right]$$

The above equation can also be expressed as

$$C_{ORA} = \frac{1}{\ln(2)}\frac{(\Xi)^{\frac{\alpha+1}{2}}}{\Gamma(mL)\Gamma(k)}G^{1\quad 4}_{4\quad 2}\left[\frac{1}{\Xi}\middle|\begin{matrix}1-\beta/2 & 1+\beta/2 & 1+(\alpha+1)/2 & 1+(\alpha+1)/2\\ 1+(\alpha+1)/2 & (\alpha+1)/2 & & \end{matrix}\right]$$

5.2 OPTIMAL SIMULTANEOUS POWER AND RATE ADAPTATION

When both the transmitter and receiver having perfect channel information, then the channel capacity for optimal rate adaptation is given by

$$C_{OPRA} = B\int_{\gamma_\circ}^{\infty}\log_2\left(\frac{\gamma}{\gamma_\circ}\right)f_\gamma(\gamma)d\gamma$$

[18]

where*B* is the channel bandwidth (in Hz) and ɣ0is optimal cutoff SNR level below which transmission will not take place [12]. This optimal cutoff must satisfy:

$$\int_{\gamma_\circ}^{\infty}\left(\frac{1}{\gamma_\circ}-\frac{1}{\gamma}\right)f_\gamma(\gamma)d\gamma = 1$$

[18]

5.3 CHANNEL INVERSION WITH FIXED RATE

The channel capacity for channel inversion with fixed rate (CIFR) requires that the transmitter exploits the channel state information so that constant SNR is maintained at the receiver [12]. This method uses a fixed transmission rate since the channel after fading inversion appears as an additive white Gaussian noise channel [19]. The channel capacity with fixed channel inversion rate can be expressed as

$$C_{CIFR} = \log_2\left(1 + \frac{1}{\int_0^\infty \frac{f_\gamma(\gamma)}{\gamma} d\gamma}\right)$$

CCIFRin the terms of MGF can be expressed as:

$$C_{CIFR} = \log_2\left(1 + \frac{1}{\int_0^\infty M(s)\, ds}\right)$$

the channel capacity for channel inversion with fixed rate policy is expressed as:

$$C_{CIFR} = \log_2\left(1 + \frac{\overline{\gamma}\ (m-1)(k-1)}{km}\right)$$

5.4 TRUNCATED CHANNEL INVERSION WITH FIXED RATE

The CIFR suffers a large capacity penalty relative to other techniques because a large amount oftransmit power is required corporate for the deep channel fades [12]. However, the truncated CIFR is a better approach than CIFR, where the channel fading is inverted above a fixed cutoff SNR(γ0). The truncated CIFR policy improves the channel capacity compared to CIFR policy at the expense of outage probability. The **c**apacity for truncated CIFR is defined as

$$C_{TCIFR} = B\log_2\left(1+\frac{1}{\int_{\gamma_0}^{\infty}\frac{f_\gamma(\gamma)}{\gamma}d\gamma}\right)(1-P_{out})$$

Where Pout is the outage probability and can be expressed as:

$$P_{out} = 1-\frac{(\Xi\gamma_0)^{(\alpha+1)/2}}{\Gamma(mL)\Gamma(k)}G_{1\;\;3}^{3\;\;0}\left[\Xi\gamma_0\middle|\begin{matrix}1-(\alpha+1)/2 \\ -(\alpha+1)/2 \quad \beta/2 \quad -\beta/2\end{matrix}\right]$$

RESULT

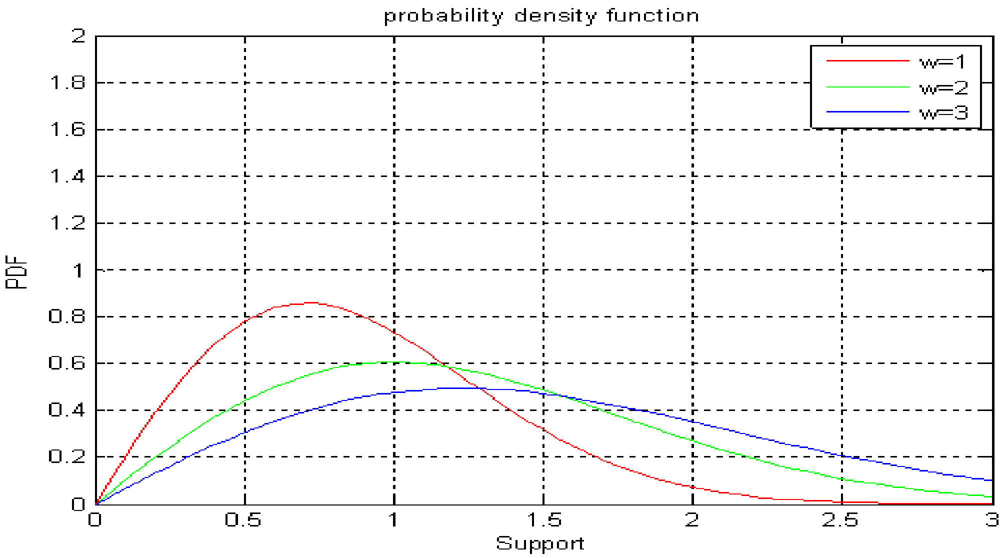


Fig:- 6.1Rayleigh distribution using Nakagami PDF function for m=1

The graph in fig4 depicts the PDF of same signal under different power conditions. Since, we have specified the value of fading parameter m=1 therefore this Nakagami distribution turns into Rayleigh distribution.

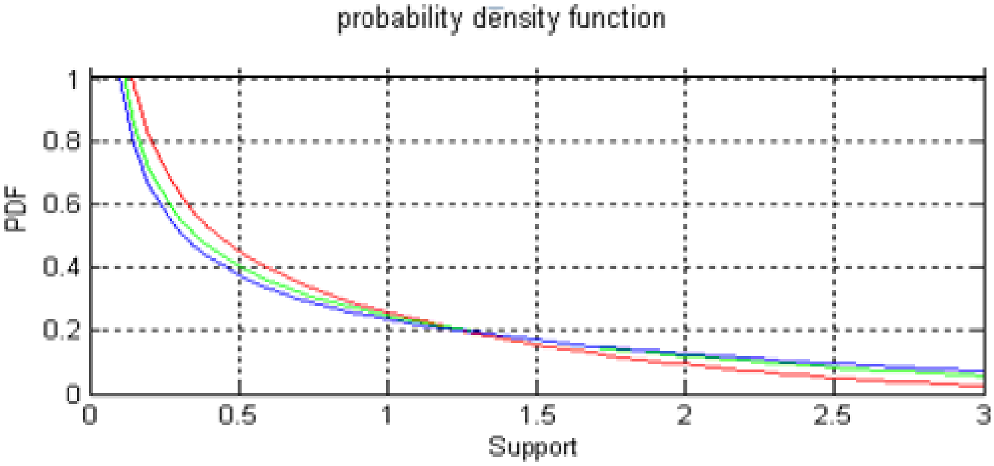


Fig6.2:-Rayleigh distribution using Nakagami PDF function for m=0.2

The graph in fig5.2 depicts the PDF of same signal under different power conditions for the fixed fading parameter value i.e. m=0.2.The distribution then reduces to a fading even more severe than Rayleigh fading.

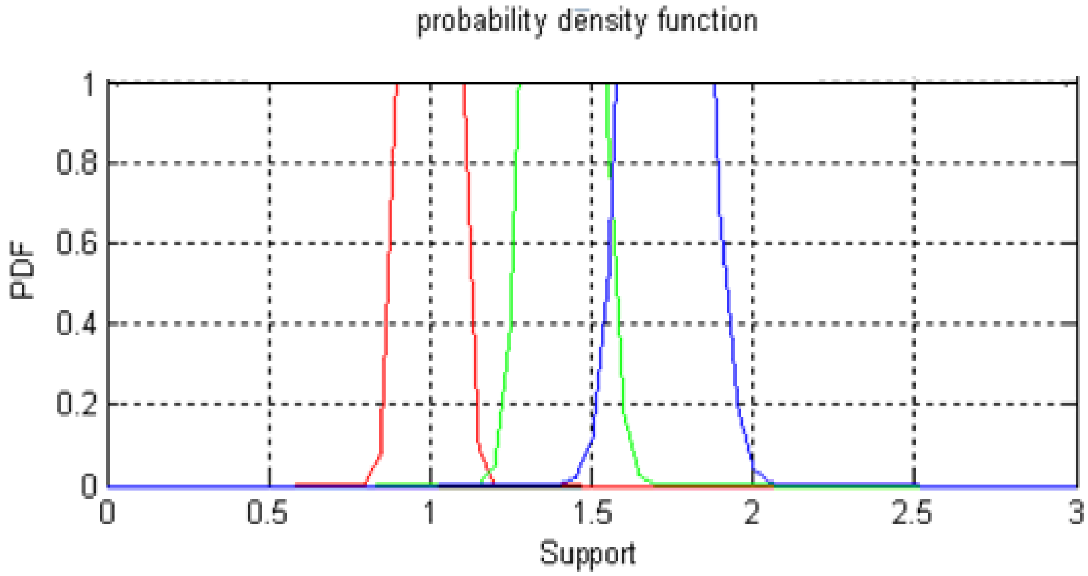


Fig:-6.3Nakagami PDF function for m=100

The graph in fig5.3 gives the PDF of same signal under different power conditions for m=100.Under this condition fading is rarely observed.

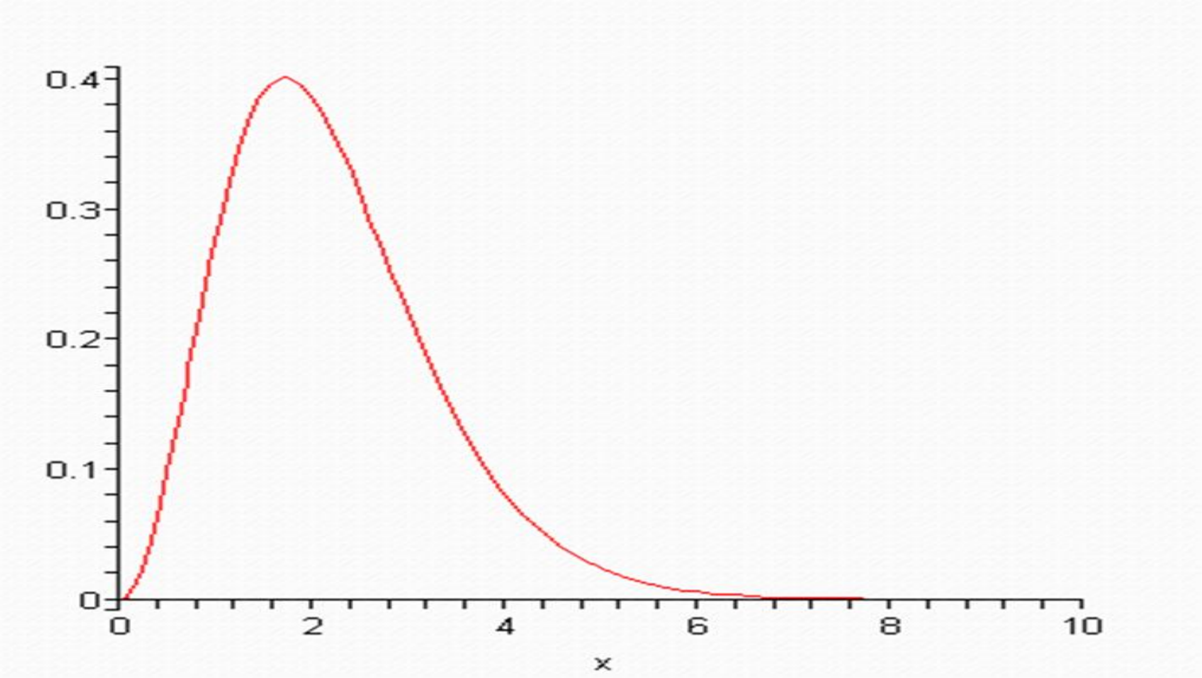


Fig:-6.4 PDF of Generalized-K Function for omega=1

The generalized-k probability density function when mean power is 1. Nakagami-m and Rayleigh-lognormal distributions do not have any closed-form mathematical solution, therefore it is difficult to use it widely. They have been approximated by the Generalized-K distribution.

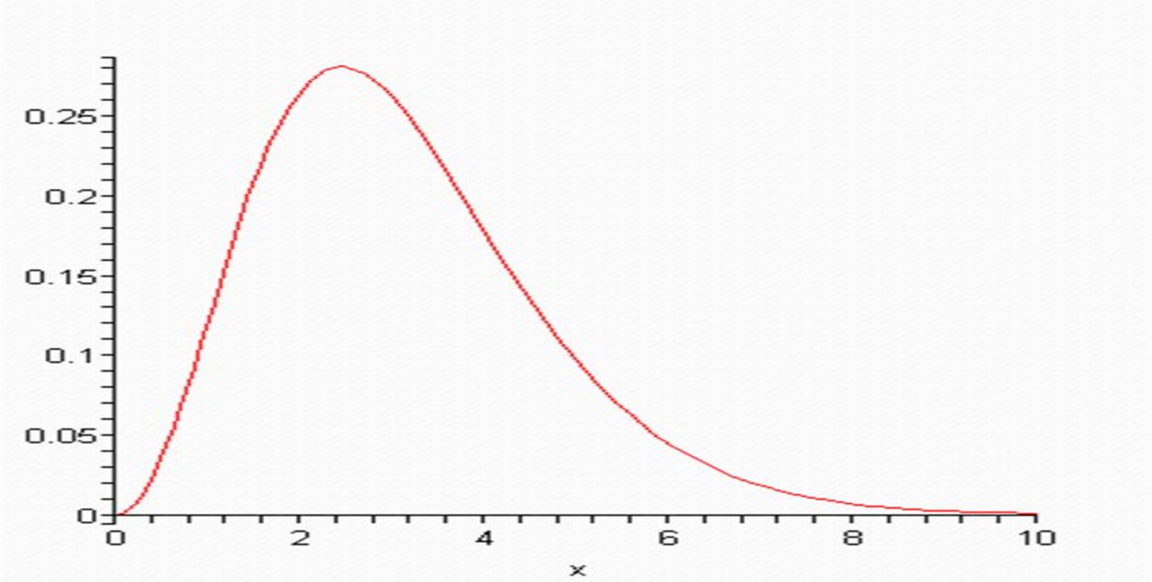


Fig6.5:- PDF of Generalized-K Function for 2nd moment E[X^2]

The generalized-k probability density function when we consider the second moment. We have taken the formula:

$E[X^2] = \frac{\Gamma(m+2)\Gamma(k+2)}{\Gamma(m)\Gamma(k)} \text{x} (\frac{i}{k*m})^2$

The performance has deteriorated as we can see the span of the graph increases.

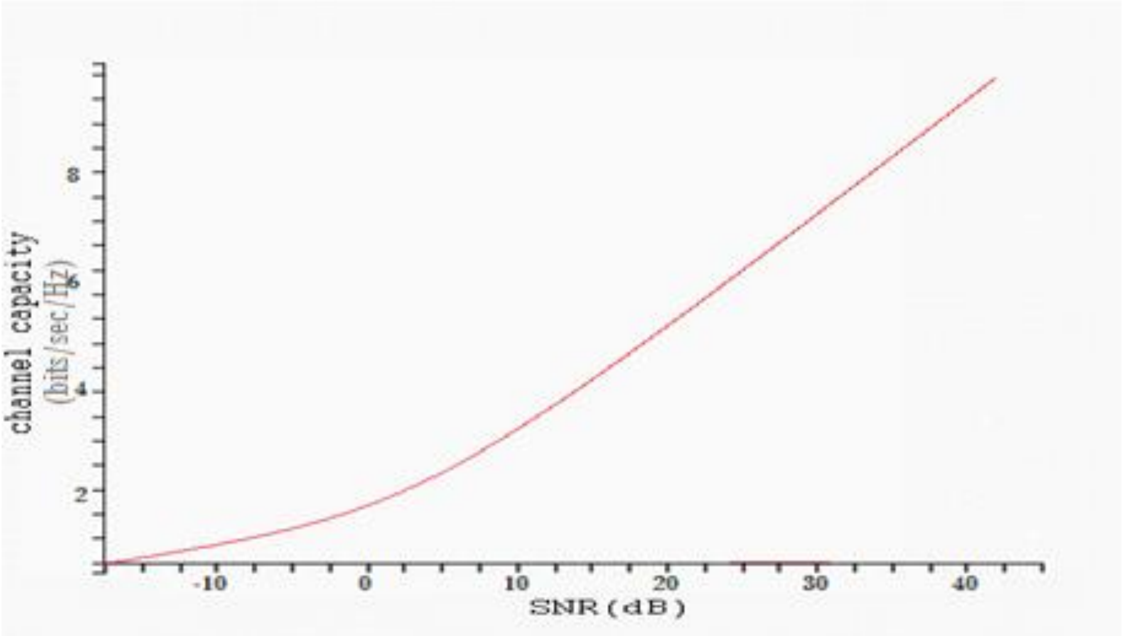


Fig6.6:- Optimal rate adaptation with constant transmit power for light shadowing

Fig 6.6 shows the channel capacity for optimal rate adaptation (CORA) versus SNR. As the value of diversity L increases the channel capacity increases. It also increases with the value of m as it was in the case of Nakagami Probability Distribution Function.

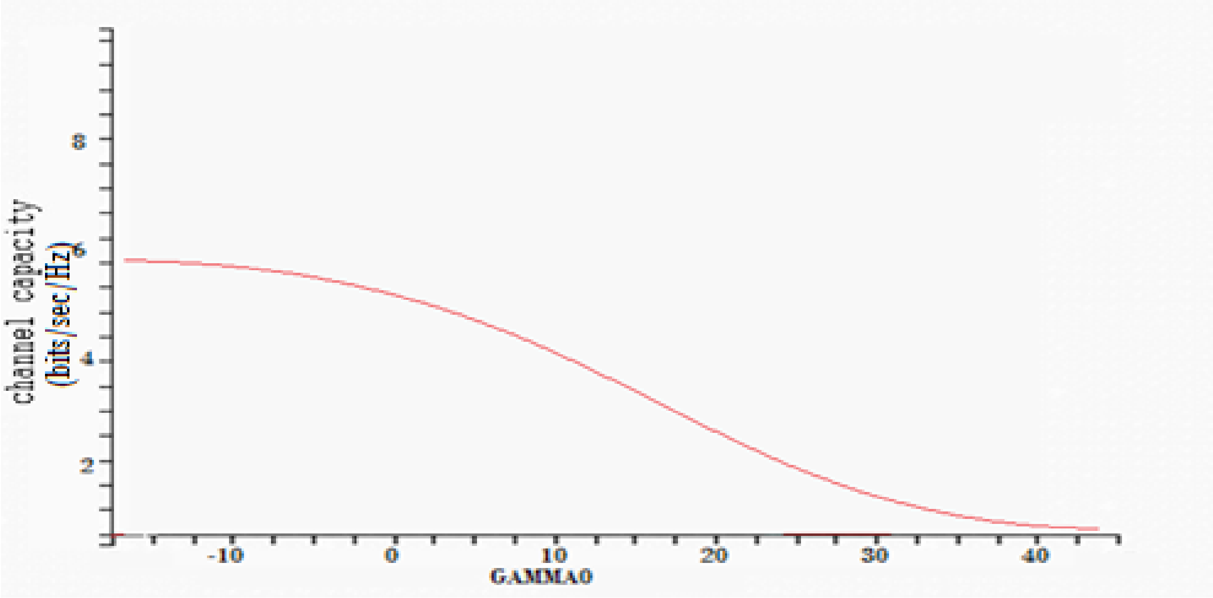


Fig6.7:- Truncated channel Inversion Fixed Rate for k=75(light shadowing)

The Figs. 7 and 8 shows the channel capacity for truncated channel inversion with fixed rate (*TCIFR*) as a function of the SNR for light shadowing and heavy shadowing .For the heavy shadowing, the channel capacity improves less with increase of the SNR and for light shadowing (*TCIFR*) increases rapidly. In this case also with the increase in m channel capacity increases.

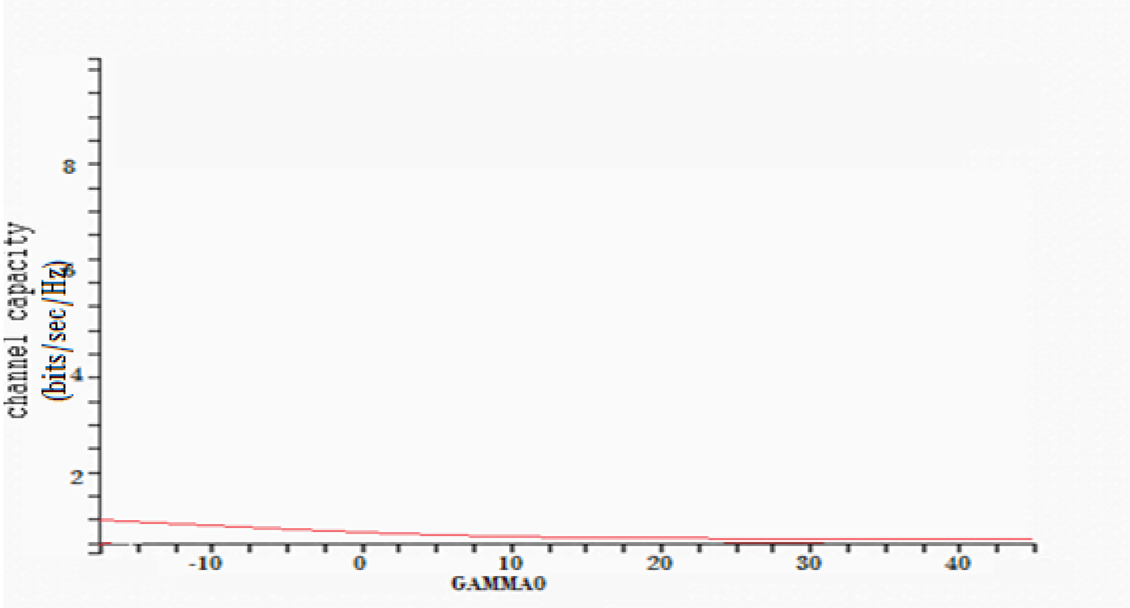


Fig6.8:-TCIFR for k=1.0931(light shadowing)

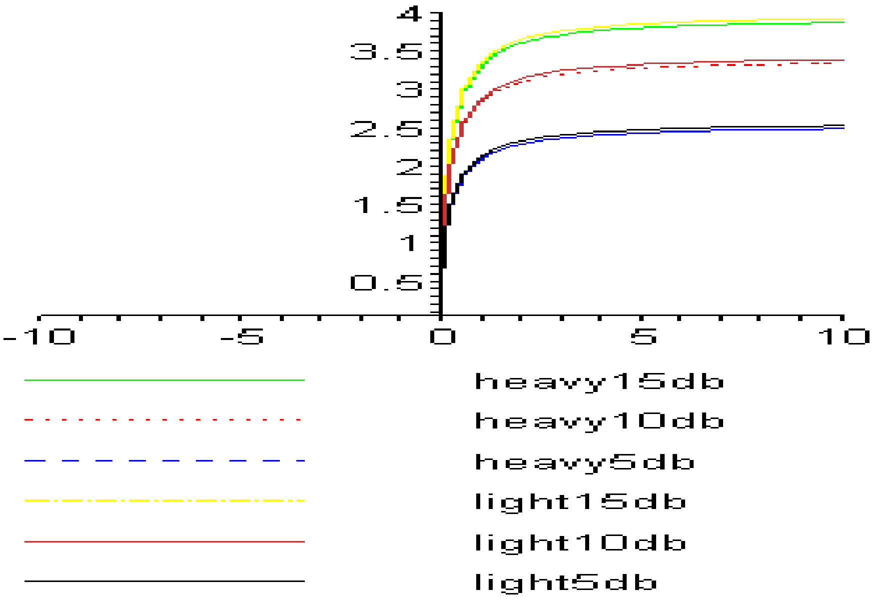


Fig 6.9:-CORA for different diversity and shadowing parameter

Shadowing Parameter k=10.093 (heavy shadowing) and k=75(light shadowing) have been used to determine the change in channel capacity with optimal rate adaptation and for different diversity parameter ‘m’.

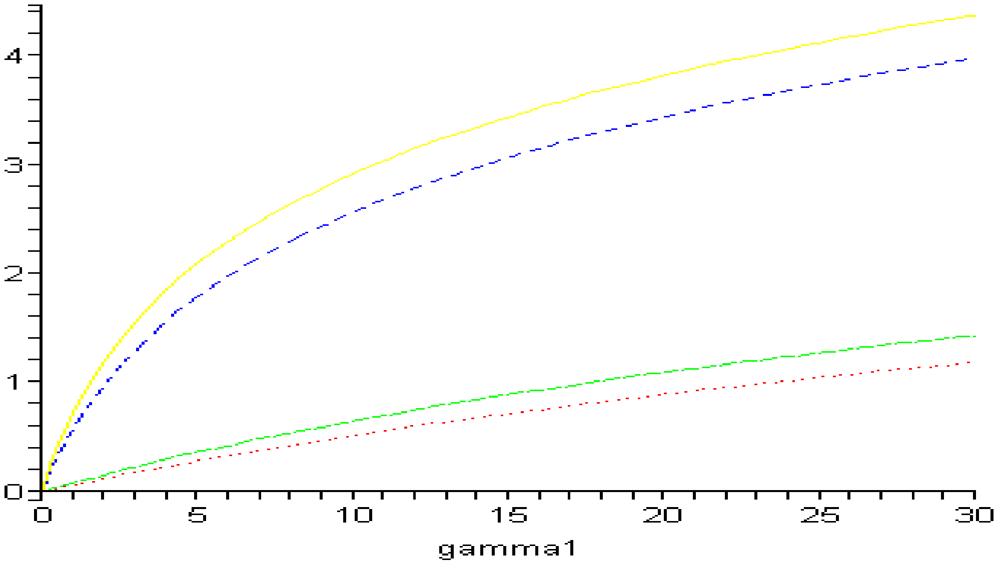


Fig 6.10 CIFR for different values of SNR

Red(m=2;light shadowing) Green(m=3;light shadowing);Blue(m=2;heavy shadowing) Yellow(m=3;heavys shadowing)

Channel capacity for the channel inversion with fixed rate (*CCIFR*)versus SNR for various values of the light shadowing (k = 75.11) and heavy shadowing (k = 1.0931).

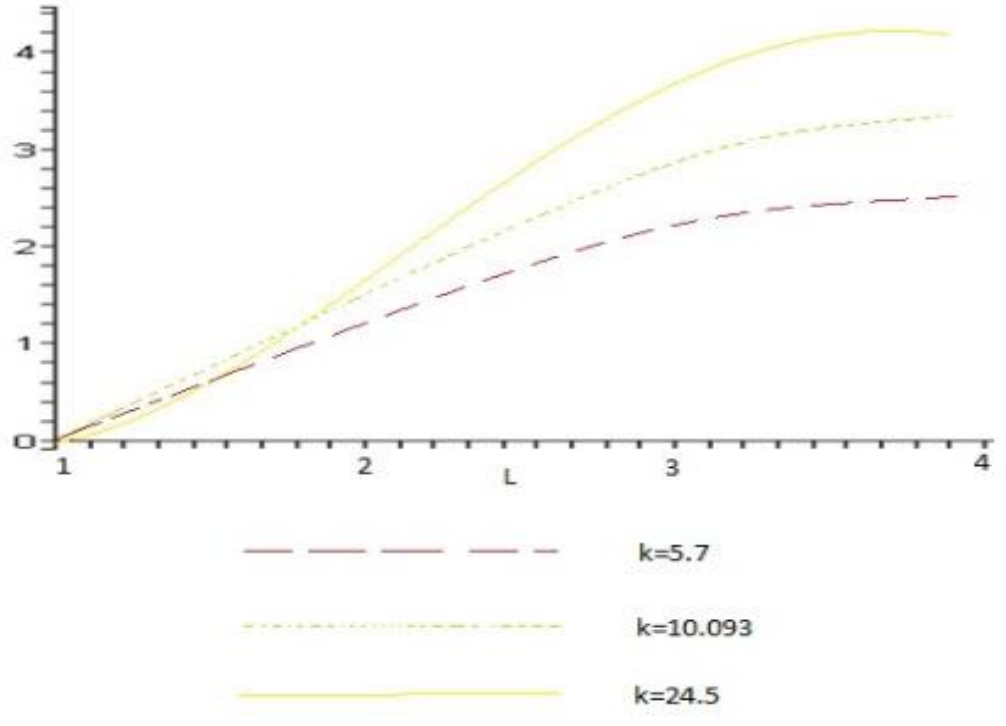


Fig 6.11 TCIFR for different values of diversity

This graph shows that as the value of ‘k’, i.e., the shadowing parameter increases, the value capacity based on truncated channel inversion increases. For heavy shadowing the value of capacity is less than what it is for light shadowing as the diversity (L) increases.

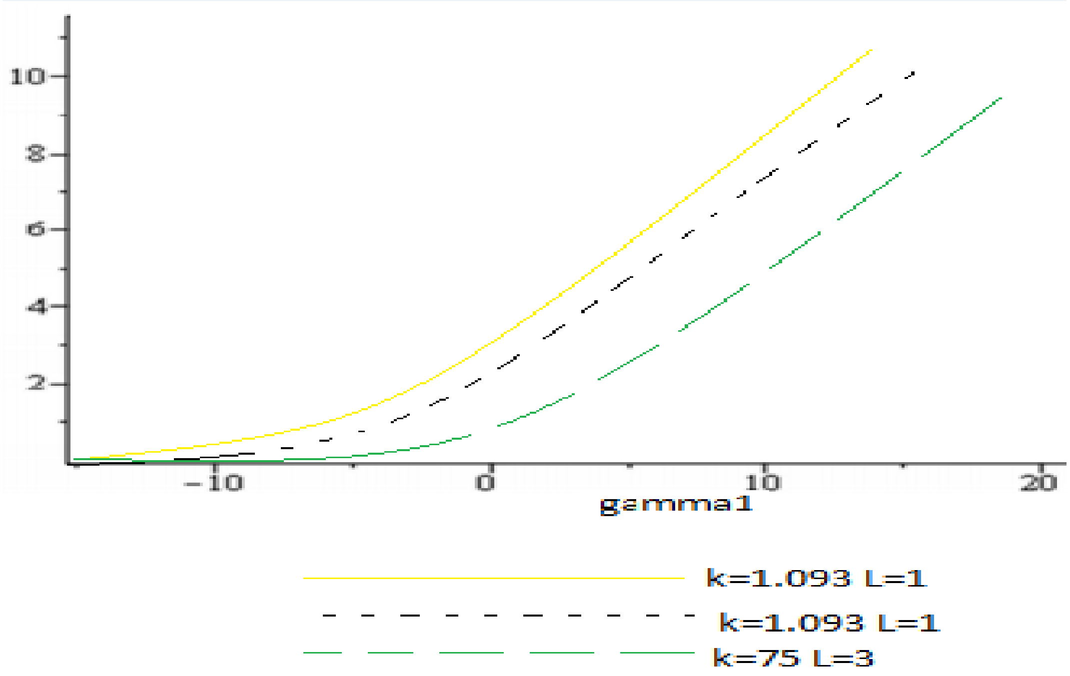


Fig 6.12 COPRA for different values of SNR

The transmitter adapts its power and data rate to the channel variations by allocating high-power levels and rates for good channel condition and low power levels and rates for the bad channel condition. Thus, for higher values of SNR channel capacity increases and is higher for heavy shadowing.

CONCLUSION

After the fourth generation communication technology has come into play there is a continuous struggle to bring the fifth generation communication technology alive. Researchers are focusing on MIMO technology, millimeter wave technology and cognitive radio technology to make this dream of faster wireless communication come true. Multiple-antenna (MIMO) technology is becoming mature for wireless communications and has been incorporated into wireless broadband standards like LTE and Wi-Fi. The frequency range of millimeter wave is from 25GHz to 300GHz. Its data rate is expected to be 40 to 100 times faster than that of today's wireless LAN technologies. Whereas CRs uses Dynamic Spectrum Access (DSA) to identify spectrum not being used, detects and mitigates interference, locks on a signal etc.

However the signal transmission over a channel is quite complex and is accompanied with various signal degradation factors such as shadowing, fading etc. Hence to model a channel for fifth generation communication technology encompassing all the degrading factors here, we have described the various probability distribution functions for channel fading and for this purpose we have made use of MGF based approach and CF base approach. In order to represent the fading phenomenon of various channels which is encapsulating the effects of both light fading and heavy fading Nakagami-m and Rayleigh distributions are employed. Therefore, to give these distributions a mathematical form generalized K fading, k-fading, MGF based distributions such as CORA, COPRA, CCIFR and CTCIFR are brought into consideration.

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