THEORETICAL ANALYSIS OF RESOURCES OPTIMIZATION AND EVALUATION FOR CELLULAR NETWORKS

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ABSTRACT

This research presents three cases of theoretical analysis for resources optimization and evaluation for cellular network. Firstly, the protocol for voice and data services in code division multiple access (CDMA) system was proposed. The voice traffic was initially served and the leftover of resources was dedicated for data. The transmission rates were computed to minimize the maximum completion time of transmission and maintain the total interfering power minimization. Secondly, the data rate optimization of each femto cell was presented under the signal quality guarantee via SINR (signal to interference plus noise ratio). The non-linear expression of data rate was maximized by linear programming method which is simpler than any other previous work. Hint that all essential parameters, bandwidth, number of neighboring cells, interfering power and others were also taken into account. Finally, the forms of the uplink spectral efficiency of non-orthogonal multiple access (NOMA) in Rayleigh and Nakagami channel were introduced. Channel gains were modeled to Rayleigh and Nakagami. Besides, numbers of active users were realistically considered as binomial and Poisson random variable. All numerical results from this research work benefit system performances as well as provide the benchmark for other related work.

KEY WORDS: CROSS LAYER PROTOCOL/ RATE OPTIMIZATION/ UPLINK SPECTRAL EFFICIENCY

88 pages

การวิเคราะห์เชิงทฤษฎีของการหาค่าที่เหมาะสมที่สุดของทรัพยากรและการประเมินสำหรับโครงข่ายเซลลูล่าร์
THEORETICAL ANALYSIS OF RESOURCES OPTIMIZATION AND EVALUATION FOR CELLULAR NETWORKS

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บทคัดย่อ

งานวิจัยนี้นำเสนองาน 3 ประเด็นที่เกี่ยวกับการวิเคราะห์เชิงทฤษฎีของการหาค่าที่เหมาะสมที่สุดของทรัพยากรและการประเมินสำหรับโครงข่ายเซลลูล่าร์ ประเด็นแรกนำเสนอโพรโทคอลสำหรับให้บริการเสียงและดาต้าในระบบการเข้าถึงตัวกลางแบบแบ่งรหัส CDMA ซึ่งระบบจะทำการให้บริการเสียงเป็นอันดับแรก และจากนั้นทรัพยากรที่เหลือที่จะถูกนำไปให้บริการแก่ดาต้า โดยอัตราการส่งผ่านจะถูกคำนวณเพื่อหาค่าที่น้อยสุดของระยะเวลามากที่สุดที่ใช้สำหรับการส่งและรักษาการหาค่าที่น้อยที่สุดของค่าพลังงานแทรกสอดผลรวม ประเด็นที่สองได้นำเสนอการหาค่าอัตราข้อมูลที่เหมาะสมสำหรับแต่ละเฟมโต้เซลล์ภายใต้การรับประกันคุณภาพของสัญญาณผ่านอัตราส่วนระหว่างสัญญาณต่อผลรวมสัญญาณแทรกสอดและน้อยส์ SINR เราหาสมการไม่เชิงเส้นของอัตราสูงสุดโดยวิธีโปรแกรมมิ่งเชิงเส้นซึ่งเป็นวิธีที่ง่ายกว่างานอื่นๆ ที่ออกมาก่อนหน้า หมายเหตุว่า พารามิเตอร์ที่จำเป็นทุกตัว ได้แก่ แบนด์วิดท์ จำนวนเซลล์รอบข้าง พลังงานแทรกสอดเป็นต้น ถูกพิจารณาด้วยเช่นกัน ในประเด็นสุดท้ายแบบฟอร์มของการหาค่าประสิทธิภาพสเปกตรัมแบบอัพลิงค์สำหรับการเข้าถึงตัวกลางแบบไม่ตั้งฉาก NOMA ในสภาพช่องสัญญาณแบบเรย์เลห์และนาคากามิได้ถูกนำเสนอ โดยอัตราขยายของช่องสัญญาณถูกจำลองแบบเรย์เลห์ และนาคากามิ ยิ่งไปกว่านั้นจำนวนผู้ใช้ที่ใช้บริการถูกพิจารณาอย่างเป็นไปได้จริงในรูปแบบของตัวแปรสุ่มทวินามและตัวแปรสุ่มปัวส์ซง ซึ่งผลลัพธ์เชิงตัวเลขทั้งหมดของงานวิจัยนี้มีประโยชน์ต่อสมรรถนะของระบบให้เกณฑ์มาตรฐานสำหรับงานอื่นๆที่เกี่ยวข้อง

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LIST OF ABBREVIATIONS

Symbols	**Definition**
β	Path loss exponent
d_i, d_j	Distance from the femto cell user to femto cell *i, j*
δ_{i}	SINR of femto cell *i*
Δ_i	Power portion of user *i*
Δ_d	Power portion of data traffic
Δ_v	Power portion of voice traffic
E	Expected value of random variable
E_b	Energy per bit
G	Spreading gain
$\Gamma_{\min}$	Minimum allowance SINR of femto cell
h_{xx}	Channel gain
γ_d	Minimum acceptable E_b / N_o of data traffic
γ_i	Minimum acceptable E_b / N_o of user *i*
γ_v	Minimum acceptable E_b / N_o of voice traffic
η_o	Background noise power density
k_d	Number of inactive data users
k_v	Number of inactive voice users
K	Number of users (in general case)
K_d	Number of data users
K_v	Number of voice users
λ	Average number of active UE

LIST OF ABBREVIATIONS (cont.)

Symbols	Definition
L	Number of subcarrier
L_{xx}	Message length
m	Nakagami fading index
M	Number of femto cells
N	Number of users
$\overset{o}{N}$	Noise power
N_o	Noise power density
P_{xx}	Transmitted power
$P_{i_{\max}}$	Maximum transmitted power of user *i*
Pr	Probability
r_{avg}	Average transmission rate of all data users
r_d	Transmission rate of data traffic
r_i	Required transmission rate of user *i*
r_{syn}	Transmission rate of synchronization
r_v	Transmission rate of voice traffic
R	Bit rate
R_{fi}	Transmission rate of femto cell *i*
R_i	Transmission rate of user *i*
S	Average modulating signal power
T	Bit duration
w_i	Index of special areas
W	Bandwidth (Hz)

CHAPTER I
INTRODUCTION

1.1 Background and Problem Statement

Wireless communication is the most authoritative and accessible to communicate with one another around the world, especially cellular networks or mobile communication, because it can connect to multiple devices simultaneously and service anywhere. Each cellular service area is separated into small regions called cell which has base station act as transmitter. Moreover, cellular industry has grown both in term of technology and its subscribers, we can see obviously people who use mobile devices such as cell phones, smartphones, laptops, tablets, smart watches, etc., at any public places and there are several new devices launched in every year. There are many benefits in our routine for cellular systems, for example, almost teenagers employ social network by their phones to update news, read electronic books, share their pictures, ideas and activities with their friends, surf in the internet and listen to music. Some business man use devices for meeting via video conferences, negotiating with their clients, searching for information and doing some projects across countries. In addition, lots of scholar use them to learn, search some knowledge and update new information for their interesting instead of the old way which we must go to library to figure out answers. Consequently, this is the better and easier way to accumulate piles of information from all over the corner of libraries in the blink of an eye. As above mentioned benefits of cellular, the great number of subscribers have still increased nowadays; therefore, over many decades, the cellular communication has been revolutionized to response its users demand and change the way people communicate.

The first generation (1G) systems used analog signal to transmit for voice services only. People could not send any data or pictures at that time. While these system severed a good voice quality of voice, they provided limited spectral efficiency and suffered from handover. Moreover, signals were easily meddled by interferences and base stations were not enough in service areas. Additionally, eavesdropping and preventing of transmission was a main trouble and devices in this era were big, heavy and expensive as well. Voice traffic is multiplexed by FDMA (frequency division multiple access) technology [1].

Then, the second generation (2G) systems took place and were a great improvement from 1G systems by using digital multiple access technology, such as TDMA (time division multiple access) and CDMA (code division multiple access). Capacity increase was one of the main motivation for these systems. Moreover, 2G systems also offer security: encryption of data and signaling messages transmission and authentication to ensure the right people are using the network, and they have enhanced data rate [2]. These systems provided mainly voice services, and they gradually evolved to support data services such as electronic mail (e-mail), Internet access, and short messaging service (SMS).

The third generation systems (3G) has been improved to provide several times higher data speed transmission, enhanced audio and video streaming for their subscribers, advanced multimedia access and global roaming; furthermore, they focus on making a wide range of services, both voice and data available to subscribers, providing the best quality of service as possible and offering services over a wide coverage area while capacity is improved. 3G systems are mostly used with mobile phones which are connected to the internet so that we can use variety of multimedia applications in this era such as video conferencing, e-commerce, global positioning system (GPS), watching television through the internet etc. However, some applications is not good enough to service their user demands [3].

The early cellular networks suffered from many limitations and transmitted mainly speech. The fourth generation systems (4G) are able to provide faster speeds by using of multiple antenna arrays at both the transmitter and receiver to improve communication performance and mainly emphasize on integration of all kinds of services like web access, file transfer and fax with the conventional voice services. The cellular networks are now heading towards all IP-based network. These systems enable connect across a wide range of access technologies and networks such as wireless local area network (WLAN), Bluetooth, wireless personal area network (WPAN), CDMA, WCDMA, and PSTN etc. Therefore, these systems are better than in every term of previous cellular networks [4], [5].

However, providers still look forward to improve and enhance the quality of service for their subscribers, the next generation systems are occurred and known as the fifth generation (5G) which changes the way to use cell phones within very high bandwidth. 5G has to be able to manage traffic of many orders, provide higher data rates that today's deployments, allow tremendous number of devices to be connected simultaneously to the network and also provide increasing capacity [6].

As mentioned of evolution in cellular communication, the quality of service is the main challenge that the providers have to consider to serve their subscribers. There are various factors that decrease quality of signal and reliability of system services. For example frequencies is limited for services, noise and interferences interrupt the desired signals; moreover, circumstances and environments also have an effect on the path of signal's transmission. As a result, there are various methods to enhance and improve performances of cellular communication, such as cell splitting, using small cells in an existing cell to improve the quality, power control technique to mitigate interferences, etc. Consequently, we will narrate more detail about wireless communication in chapter 2 from some work.

1.2 Research Objectives

This research is to propose the new techniques and models considering the quality of service in the different era of cellular communication, therefore the research objective can be classified as below;

- To theoretically analyze the performances, for instance bit error rate, signal-to-interference-plus-noise ratio (SINR), signal-to-noise ratio (SNR), channel capacity, outage probability, etc. in the physical layer of cellular network
- To propose mathematical models for resources optimization, for example frequencies, communication channels, transmitted power, bandwidth, of modern cellular networks with the guarantee of quality of services.
- To propose a new mathematics models to calculate uplink total spectral efficiency under both Nakagami and Rayleigh fading environments.

1.3 Scope of Work

The scope of work is defined as follow;

- The cross layer protocol on uplink CDMA is considered for integrated voice and data traffics
- The parameters for the cross layer protocol are used IS-95 CDMA based system.
- Our protocol is compared with conventional CDMA by optimization of parameters, such as number of data users, message lengths, delay of message etc.
- Rate optimization for femto cell is proposed in term of downlink by linear programming.
- The parameters of rate optimization, number of neighboring femto cells, interfering power, bandwidth and the background noise power, is computed under SINR constraints.
- The uplink spectral efficiency of NOMA is presented in two channel model, namely Rayleigh and Nakagami fading channel models.
- The new spectral efficiency is evaluated in which channel gain and number of users are random variable.
- All numerical results are calculated by computer simulation.

1.4 Action Plan

No.	Activities	2013				2014											
		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.	Studying cellular networks	■	■														
2.	Analysis Code Division Multiple Access (CDMA) technology			■	■												
3.	Proposing a new strategy to minimize the maximum transmission time					■	■	■									
4.	Simulation and conclusion the results								■	■	■						
5.	Studying modern cellular networks											■	■				
6.	Analysis interference management approaches and non-linear and linear programming													■	■		
7.	Proposing a way to maximize date rate of femto cell by linear programming														■	■	
8.	Simulation and conclusion the results																■

No.	Activities	2015										
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
9.	Simulation and conclusion the results (cont.)	■										
10.	Studying and analysis future radio access		■	■	■							
11.	Proposing a new mathematics models to compute uplink spectral efficiency in Rayleigh fading					■	■					
12.	Simulation and conclusion the results						■	■				
13.	Proposing a new mathematics models to compute uplink spectral efficiency in Nakagami fading								■	■		
14.	Simulation and conclusion the results									■	■	
15.	Writing up manuscript										■	■

1.5 Thesis Outline

There is thesis outline arrangement as follow; firstly, overview cellular communication is presented in chapter 2. Basic of wireless communication, cellular concept and infrastructure are described to understand the overall information. Several air interface techniques and challenges are illustrated to connect subscribers to service network and have an effect on the cellular communication, respectively. Strategies (i.e. cell splitting, cell sectoring, umbrella cells and femto enhancement) are analyzed to improve performances from the effects. Future technology in communication is also described. From the chapter 3 to chapter 5, we propose the work regarding enhancement performances in the system in various generation of technologies.

In chapter 3, optimal rate scheduling for uplink CDMA (code division multiple access) is proposed and explained thoroughly. The transmission rates are computed to minimize the maximum completion time of the transmission, and at the same time keeping the total power minimization constraint in order to maintain the overall interference to the other cells minimum. Simulation parameters and results are shown and discussed.

In chapter 4, the new rate optimization for femto cells is present to calculate data rate of each femto cell while the signal quality is still guaranteed by SINR limitations. Moreover, we optimize data rates by linear programming which is simple method. Optimization problem which is used in this chapter is represented and the results being various parameters are illustrated.

In chapter 5, the uplink spectral efficiency in Rayleigh and Nakagami fading channel models is proposed. The two channel models display an environment which the path of transmission has partial obstacles and no obstruction. In addition, random the number of user equipments is considered in both binomial and Poisson cases to show practical case in cellular communication. Numerical results are shown and discussed in term of binomial and Poisson in Rayleigh and Nakagami fading channel.

Finally, in chapter 6, conclusion from chapter 3 to chapter 5 is demonstrated; furthermore, future work is discussed. It is shown that there are various proposed ideas that are displayed to find the suitable method for each technology to improvement performances which are required in cellular communication.

CHAPTER II
LITERATURE REVIEW

2.1 Wireless Communication

Nowadays, wireless communication becomes an essential and popular factor for our parts as the power of wireless communication make the world a smaller place and convenient for our living. For example, in term of relationship, we can keep in touch with our friends by mobile phone, social networks or sending electronic mails (e-mails) anywhere and anytime in addition of spending less time. Moreover, we can update and search for some information from the internet library such as attractive places to travel, making video conference across the world, downloading some entertainments, watching television, or updating news around the world. As above mentioned utilities, everything that we can do now, in the past, we cannot employ it.

Wireless communication is the technology which allows information to be transmitted through the air without requiring wires or cables by using electromagnetic or radio waves as this result there are many advantages i.e. installment and maintenance of wireless are lower cost than wired system. Not only we have to pay the costs of wire and cable but also invest to time and labor to plan wiring routes and set up the wire in place. Wireless communication is a great deal of mobility because of traveling radio waves freely through the air. We can, for example, make a phone call while traveling in our car. Then, wireless system is easy accessible, we do not need to carry cables or adaptors in order to access network. Furthermore, wireless system is flexibility because a wireless transmitter accommodates any number of receivers; on the other hand, a wired communication system is limited to the number of connections on the equipment [7].

The basic of wireless communication network consists of wireless devices, base station and network, seen in Figure 2.1.

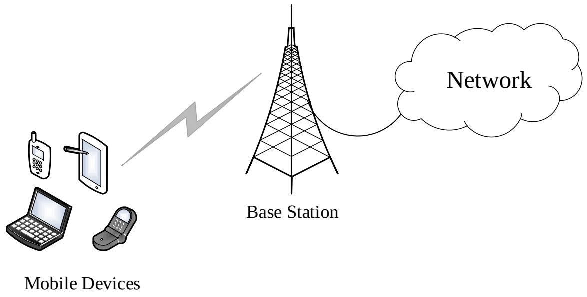

Figure 2.1 The basic of wireless communication network.

Generally, there are two types of infrastructure of wireless communication network. Firstly, cellular network consists of its own base station and core network for example mobile cellular network, service provider has to invest to core network, switching centre, and databases which collect data, profiles of users, some parameters of service. We explain more in the next section

Secondly, cordless network is a network without its own core network so that it uses core network from the other systems. For example, personal cordless telephone (PCT) network uses landline phone to be a core network and Wi-Fi uses internet network to be a core network that there is access point or router which acts to connect subscribers to core network. So we call this connecting part as air interface.

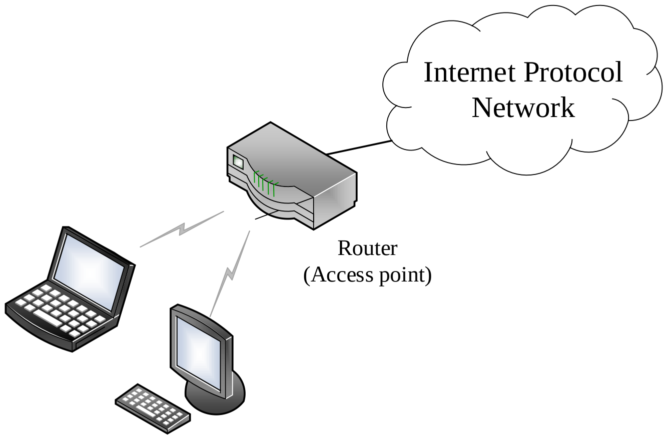

Figure 2.2 Wi-Fi infrastructure mode.

In practice, Wi-Fi, WiMAX and Cellular systems are the main of wireless technologies for servicing. Additionally, there are both advantages and disadvantages each of technologies. Wi-Fi is, stands for Wireless Fidelity, based on the IEEE 802.11

family of standards and is a local area network (LAN) to provide indoor coverage. Wi-Fi can serve around 100 meters coverage and a few users. Moreover, Wi-Fi systems are not designed to support high speed mobility. However, Wi-Fi offers the highest peak data rates than do cellular systems and WiMAX and one important advantage of Wi-Fi over WiMAX and cellular is a lot of available terminal devices which can support the system [8]. WiMAX stands for Worldwide Interoperability for Microwave Access and is based on the IEEE 802.16 family of standards. In practical terms, WiMAX operates similar to Wi-Fi but greater coverage range, and greater number of users. WiMAX network, is less complexity that cellular, consists of access service network (ASN) and connectivity service network (CSN), seen in Figure 2.3.

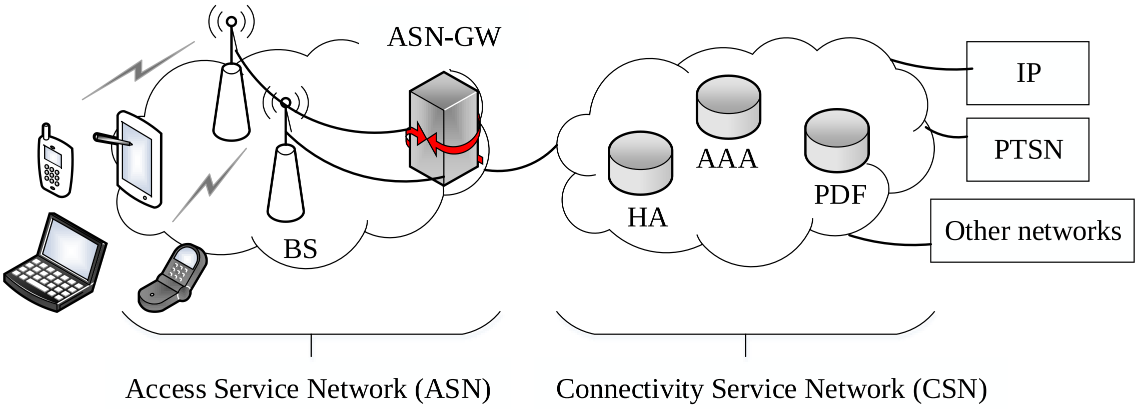

Figure 2.3 The basic of WiMAX network.

WiMAX has advantages on light weight IP network; whereas, cellular has complex and separate voice and data networks. In contrary, WiMAX lacks of devices capability and mobility capability is added-on [9].

As above mentioned advantages and disadvantages of each technology, WiMAX is a somewhat middle ground between cellular and Wi-Fi, cellular is the best and popular technology because it supports mobility. Consequently, we describe more details of cellular network in the next section.

2.2 Cellular Concept

As the previous section, there are two main types of wireless communication systems i.e. mobile cellular system and wireless internet system. Wireless internet system architecture is in the same class of cordless network architecture that means it uses other core network system. For instance wireless local area network or Wi-Fi uses internet protocol (IP) to be a core network. Router acts to be air interface part to connect equipment to IP by radio waves, seen in Figure 2.2.

Mobile cellular architecture is more complicated and more expensive costs that cordless network architecture; however, mobility management is superlatively supported by mobile cellular network. Although, increasing of subscribers is good for service providers in business aspect, frequency resource is not enough to serve a number of subscribers. Cellular concept is a major solution of limited resources, congestion and user capacity. It can offer very high capacity in limited spectrums. The cellular concept is a system which service area is split in small areas that called cell, normally in books, coverage cell or foot print of each cell is circle or hexagon in Figure 2.4. For example, in Figure 2.5, an area has two frequency bands which each band can serve only one user so capacity of the area is two users maximum in the same time. If we divide an area to three equal parts, the area can serve six users. Even if the area is split more areas, it will increase capacity of service. Each cell has a base station which is assigned different frequency bands.

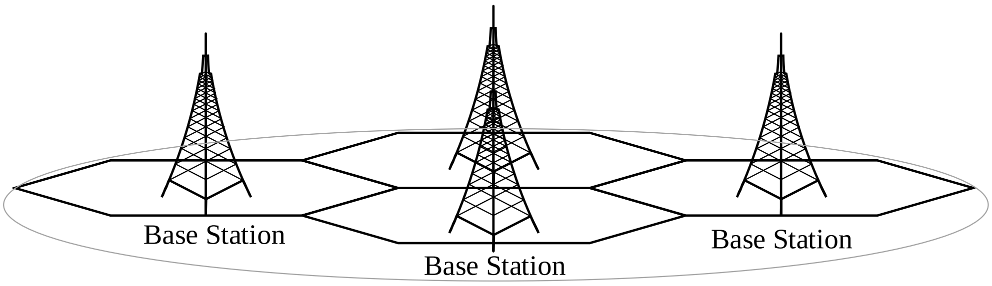

Figure 2.4 Cell Demonstrations.

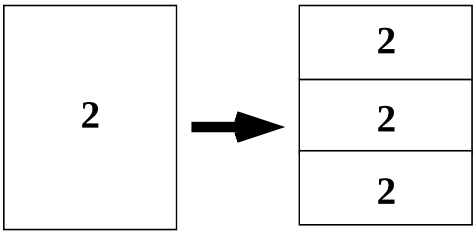

Figure 2.5 Increasing capacities by cell splitting.

As a result of the splitting area, frequency reuse, which is a technique of frequency resources management, is an advantage of capacity improvement. In Figure 2.6, system can reuse frequencies in other cells but reuse distance is far enough to not interfere with each other cells, realistically, reuse distance is one width cell. We call cells that use the same set of frequencies as cluster. Cluster has many sizes such as three, four, or seven cells [7].

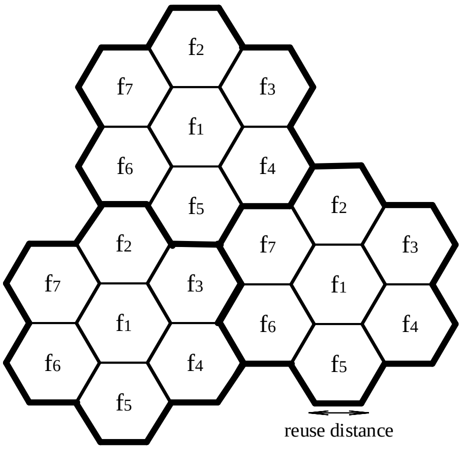

Figure 2.6 Frequency Reuse.

Normally, infrastructure of cellular network has three main parts, seen in Figure 2.7.

User equipment part is mobile phone devices which receive and transmit signals to base station through radio waves. Each device has a SIM (Subscriber Identity Module) that like an identity card to determine the right for reception services.

Air interface part, is a medium to connect subscribers to core network, has two units i.e. base station (BS) is the part which directly receive and transmit radio waves with mobile phone devices; base station controller (BSC) acts for frequency resource management of its station.

Core network part is a main operation for frequency resource management of network, tacking the status of the subscribers such as on-off status of devices, asking of services, details of services, etc. Moreover, location, mobility management, charging and billing of services of all subscribers are operated by core network. Then core network also acts as gateway to exchange information between inside network and other networks. There are databases that serve as follow in core network.

a) Mobile Switching Centre (MSC) is responsible for controlling or connecting all mobiles of network in areas

b) Operation and Maintenance Center (OMC) is for security management, network configurations, and maintenance tasks.

c) Home Location Register (HLR) is the database of keeping information about subscribers register in their MSC.

d) Visitor Location Register (VLR) is the database of containing information about subscribers who register in other MSC location areas.

e) Authentication Centre (AUC) is the database that is used to determine the right to receive services.

f) Equipment Identity Register (EIR) is the database which is used to check mobile phone devices whether they can receive services from network or not.

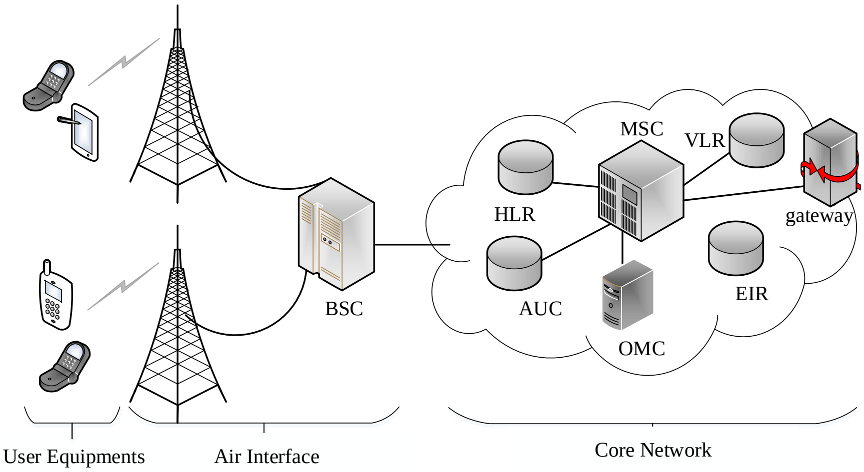

Figure 2.7 Infrastructure of cellular network.

2.3 Air Interface of Cellular Techniques

From the previous section, the air interface part of cellular system is the medium to connect subscribers to core network and BSC acts for frequency resource management. Frequency resources management is an important technique for responding a demand of subscribers such as higher speeds or data rates to support their applications, continuous service etc under resources limitation. The technique of resources management is called as media access control (MAC) that has three major accesses.

Firstly, Frequency Division Multiple Access (FDMA) that is used in the first generation (1G) of analog mobile cellular system allows each subscriber to receive service in different frequencies, in Figure 2.8. Services in the first generation emphasize on voice traffic, and then a couple of speaker uses only one frequency all the time of conversation. This is an inefficient management because there is sixty percentage of idle period, which means no sending any information, of human voice. So if we can use frequencies in idle period for other subscribers, system will be more efficient.

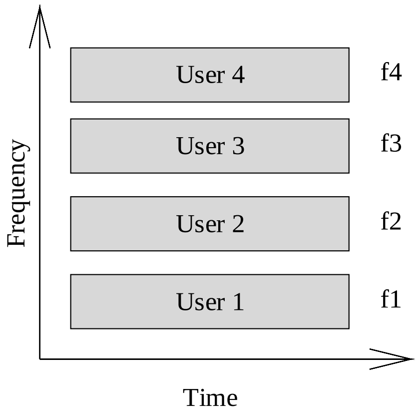

Figure 2.8 FDMA.

Secondly, information signals such as human voice, messages, pictures, etc in the second generation (2G) are transformed to be digital signals that are replaced by digit 0 and 1, and then the system will pack those signals in term of packets and send them to reserving time slots, seen in Figure 2.9. Moreover, the system can arrange remaining time slots to other subscribers in the same spectrum; this technique is called as Time Division Multiple Access (TDMA) which improves of frequency management and also increases capacity in the system. Practically, 2G mobile cellular system divides the time to be a frame that each frame has eight time slots so the system can support eight users in the same time and a subscriber can uses a time slot of each frame until the end of conversation or service.

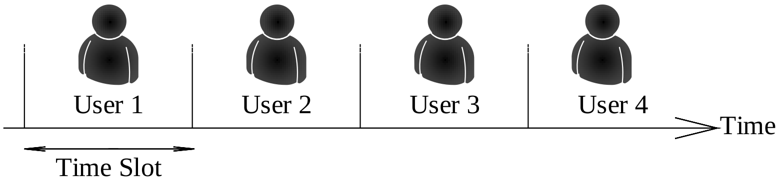

Figure 2.9 TDMA.

Thirdly, in Figure 2.10, Code Division Multiple Access (CDMA) allows all users to transmit their information at the same time and same frequency by coding; in addition, coding is the way to protect interfering between transmissions. Signals of any couple of conversation in CDMA will be encrypted thus only their couple can detect and interpret. Other signals of the couples are noise that has an impact on quality of detection and interpretation. Furthermore, CDMA capacity depends on acceptable quality of signal that means if we want high quality, capacity will be low. This appearance is known as soft capacity so CDMA differs from both capacity of FDMA and TDMA which are known as hard capacity serving fixed number of users.

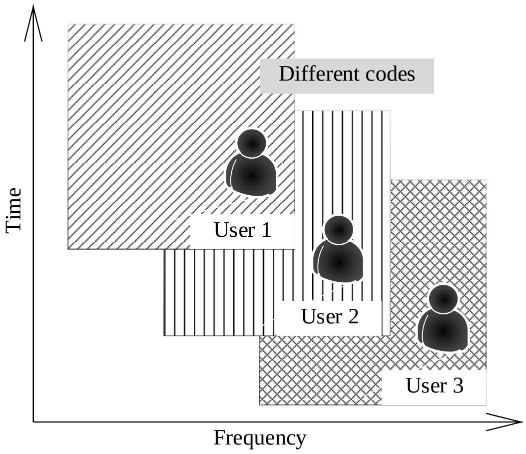

Figure 2.10 CDMA.

To sum up, frequency resources management in air interface part has been developed to be more efficient services to yield better quality for subscribers. It is not the only thing that responds quality; moreover, there are some factors which have an effect on transmitting signals in the next section.

2.4 Challenges for Cellular Communication

The main challenge of cellular communication is quality of signal that we have to consider. Radio waves, are used in wireless system, can be interfered with another sources of electromagnetic waves by natural or human and be attenuated by some obstructions such as buildings, trees, mountains, etc. There are factors that decrease quality of signal and reliability of system services. So we show some factors which have an effect on radio wave propagation for digital signal transmission in cellular communication as below.

2.4.1 Limited of resources (frequencies) is one factor that affects on service because service provider cannot serve all of subscribers by different frequencies. Accordingly, we have to find some manners to manage resources.

2.4.2 Interferences and Noises noise, which are not necessary to be same or adjacent frequency bands, are signals from other sources and middle with detecting signal of receiver, so performance of receiving signal drops. Interferences occur when receiver gets signals from more than one different source which comes from same or adjacent frequency bands, as a result, signals collide with each other. So receiver cannot receive correct signals. There are two types of interferences.

a) Co-channel interference is colliding of the same frequency band

b) Adjacent channel interference occurs when filter is not idea so that near frequency bands can interrupt frequencies at receiver. From this factor, it can cause another effect that is called near far effect. In Figure 2.11, there are two mobile stations (MS) which use adjacent frequency band, one is nearby BS and the other is far. When both MS send signal to BS, signal of near MS is stronger that far one. So BS cannot detect the signal from far one.

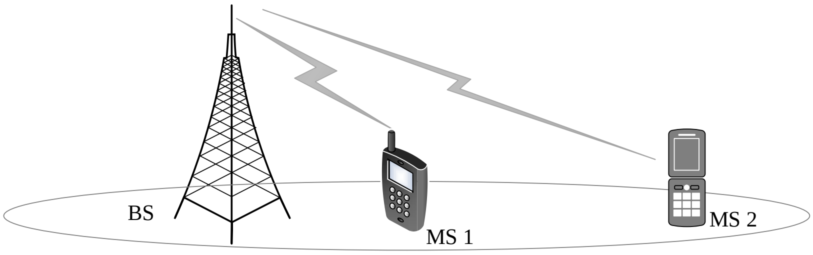

Figure 2.11 Near Far Effect.

2.4.3 Attenuation of signal happens when signals travel from a place to another location and depends on distance. Attenuation not only depends on distance but also on frequency that means attenuation rates of higher frequency is more than smaller one at same distance.

2.4.4 Fading means that amplitude of signals has changed all the time. This is the result of the same signals traveling through the air at the different time by reflection, refraction or diffraction.

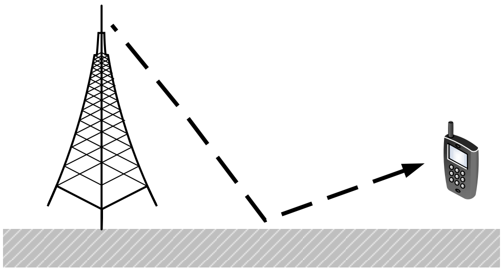

Figure 2.12 Reflection

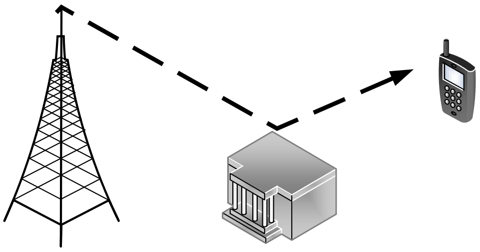

Figure 2.13 Refraction

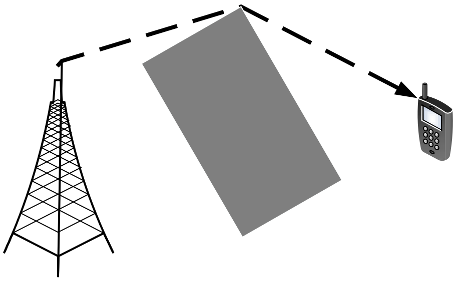

Figure 2.14 Diffraction

2.4.5 Doppler Effect is changing frequency as the result of moving of user equipment.

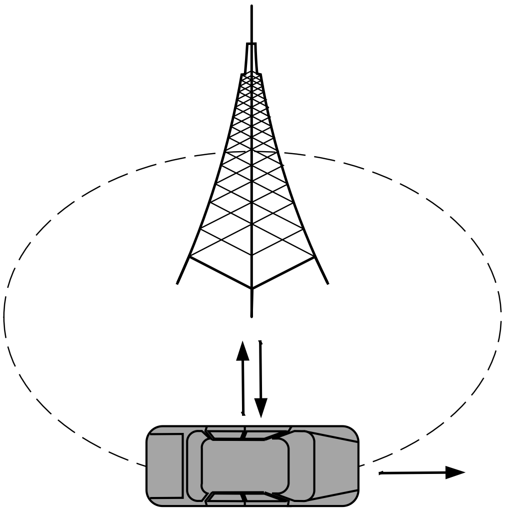

Figure 2.15 Doppler Effect

From above mentioned factors, there are many solutions to maintain and increase effectiveness of performances in cellular communication. In the next section, we show some researches to improve performances.

2.5 Strategies to Improve Performances

Handover or handoff operation in cellular system happens when MS move into different cells while having a conversation due to supporting mobility. From

Figure 2.16, MS in cell A move into cell B, normally, MS connect to BS all the time and BS has to monitor signals from BS that are strong enough to communicate. If the signals are too weak than standard, BSC will offer to make handover operation. From handover and limited resources problem, there are many strategies to improve performances and increase more capacity for cellular, we explain in subsection.

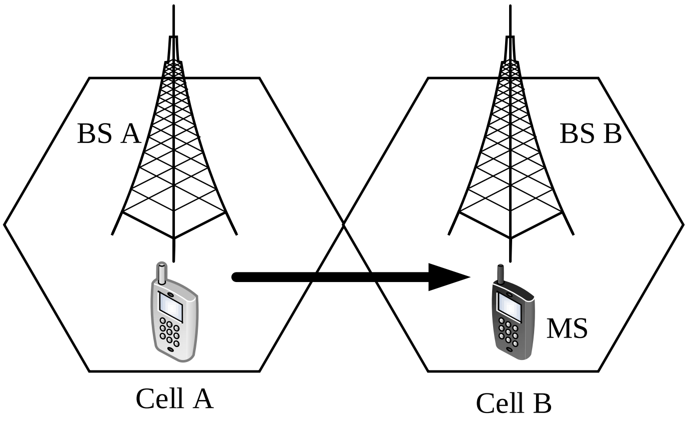

Figure 2.16 Handover

2.5.1 Cell Splitting

We raise capacity in the system by cell splitting which reduces cell size for increasing frequency reuse. This technique not only increases total capacity but also increase handovers in the system. Consequently, cell splitting is suitable to the areas which are dense of subscribers and low mobility.

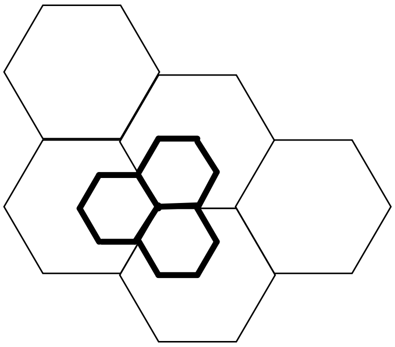

Figure 2.17 Cell Splitting

2.5.2 Cell Sectoring

This technique separates cells into sectors which each sectors use different frequency bands so that the frequency can be reused in adjacent cell. Cell sectoring achieves capacity improvement by using directional antenna that can define coverage area. A cell is normally separated into three 120° sectors or six 60° sectors.

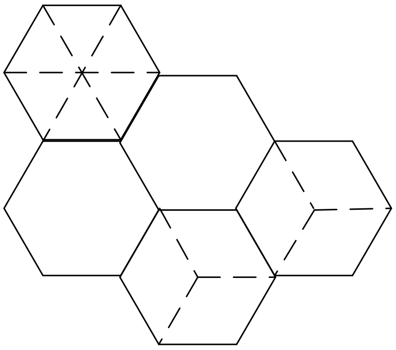

Figure 2.18 Cell Sectoring

2.5.3 Umbrella Cells

We format cells which large cell covers small cells by using different antenna heights and different power levels. Large and small cell are called as overlaid and underlaid cell, respectively. This technique provides overlaid cell to high speed subscribers while underlaid cell cover subscribers at low speeds.

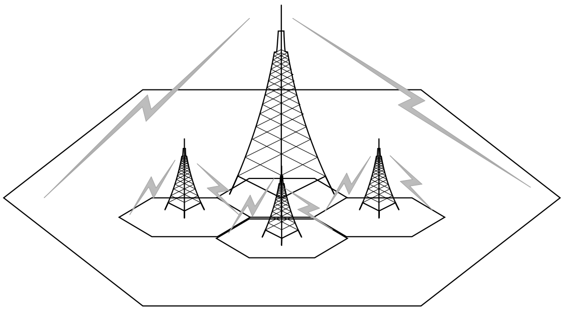

Figure 2.19 Umbrella cells

2.5.4 Femto Cells

One of the effective techniques of improving performances in cellular network is to reduce cell size and transmission distance. There are diverse cell types to deploy over macro cell for improvement. From Table 2.1 [10], consequently, deploying femto cells seems to be the best strategy to solve those problems. Femto cells are a small base station of mobile network operator for locating in accommodations and small offices because femto cells have small coverage. Femto cells connect to the cellular network via broadband communications links e.g., ADSL or fiber optics. Advantages of femto cells deployment are improvement of interior houses and buildings and indoor where macro cell signals are weak. Furthermore, femto cells can provide high date rate services and enhance capacity, they serve as low power. Then femto cell can be easily installed by users like wireless routers. Finally, femto cells can also converge to landline and mobile services.

Table 2.1 Comparison between some cell types

Properties	Cell Type		
	Microcell	Picocell	Femtocell
Power	30 dBm	30 dBm	20 dBm
Coverage range	Up to 500 m	<100 m	<30 m
Access mode	Open to all users	Open to all users	Closed subscriber group
Deployment	Outdoors	Indoors or outdoors	Indoors
Installation	By the operator	By the operator	By the user
Cost	Expensive	Cheap	Very cheap

2.6 Femto Enhancement Techniques

However, one of major challenges in femto cell networks is interferences mitigation between neighboring femto cells and between the femto cell and macro cell [11], seen in Table 2.2, because femto cells operate the same licensed spectrum as macro cell due to resources limitation that we know as co-channel deployment.

Table 2.2 Interference scenarios

Index	Aggressor	Victim	Transmission mode
1	Macro cell UE	Femto cell BS	Uplink
2	Macro cell BS	Femto cell UE	Downlink
3	Femto cell UE	Macro cell BS	Uplink
4	Femto cell BS	Macro cell UE	Downlink
5	Femto cell UE	Femto cell BS	Uplink
6	Femto cell BS	Femto cell UE	Downlink

There are different approaches for interferences mitigation.

2.6.1 Femto aware spectrum arrangement scheme

In [12], they propose femto aware spectrum arrangement scheme to avoid uplink interference between a macro cell and femto cells. The frequency spectrum for macro cell coverage is divided into two parts: macro cell dedicated and macro cell-femto cell shared spectrum. Spectrum allocation to femto cell is operated by mobile operator so that macro cell base station has to have sufficient information for sharing spectrum. From this reason, macro cell base station develop an interference pool which contain macro cell UEs nearby femto cells, then macro cell UEs are assigned to macro cell dedicated spectrum part to alleviate interference between macro cell and fem to cell. Other macro cell UEs which are not near femto cell UEs share and use spectrum with them but there is disadvantage when increasing number of macro cell users near the femto cell.

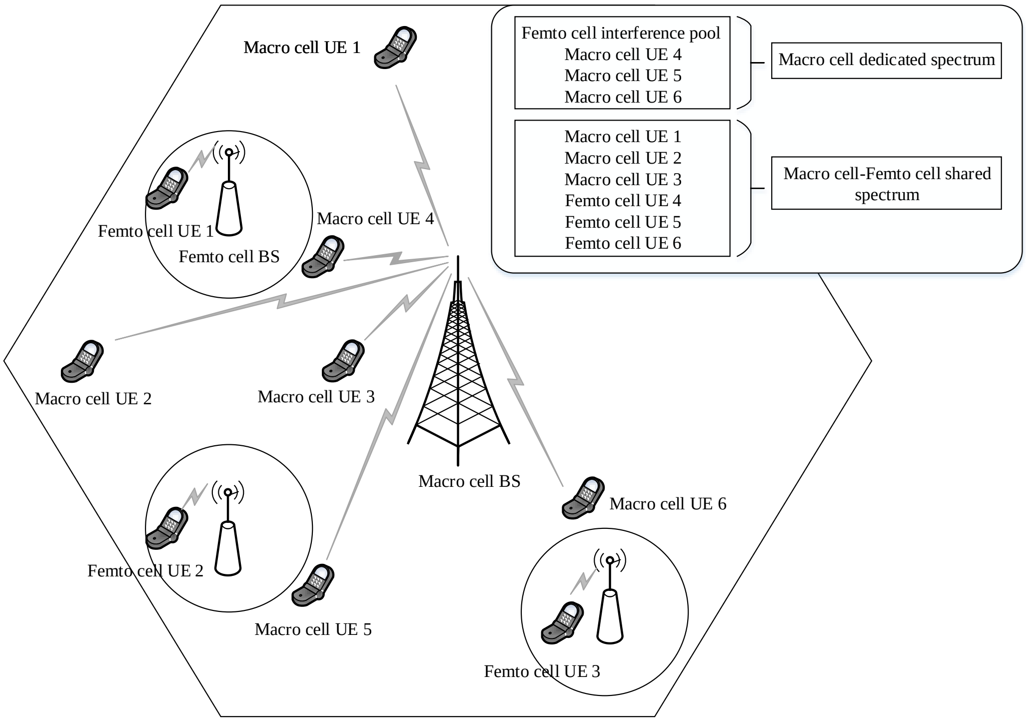

Figure 2.20 Femto aware spectrum arrangement scheme

2.6.2 Clustering of femto cells

In [13], they present clustering of femto cells to mitigate downlink interference between neighboring femto cells and between the macro cell and femto cells. In this scheme, a macro cell has a femto cell system controller which contains necessary information i.e. position of femto cells and macro cell UEs. The entire frequency band is divided to macro cell UEs first and the rest is reused by femto cells. This technique can solve macro cell UE downlink dead zone problem and maintain quality of services for users. Nonetheless, the part of frequency band sharing is defined by the number of femto cell clusters through a clustering method. Femto cell UEs are allocated into different frequency reuse clusters and femto cell UEs of different femto cell base stations in the same cluster use the same sub-channels. Calculating distance of clustering interference depends on geographical position.

2.6.3 Beam subset selection strategy

The authors in [14] propose an orthogonal random beam forming to reduce interference between macro cell and femto cell. This strategy bases on the number of macro cell UEs and the density of femto cell in the system. Macro cell selects the beam subset and the users based on the signal-to-interference-plus-noise information are feedback by macro cell UEs. The main objective is to increase throughput of the system based on adaptive selection of optimal number of beams. The adaptive selection of the number of beams can decrease interference between macro cell and femto cell and give an opportunity to femto cells to access the spectrum.

2.6.4 Fractional frequency reuse (FFR) and resource partitioning

This method divides the entire frequency spectrum into several sub-bands which each sub-band is assigned to each macro cell or sub-area of the macro cell. Interference between macro cell and femto cell is decreased because of using the different resources of macro and femto cell. In [15], they propose frequency reuse with pilot sensing to reduce interference between macro cell and femto cell. A femto cell base station which is turned on senses pilot signals of neighboring macro base stations when FFR of three or above and uses the rest sub-band that macro cell does not use. This scheme achieves to enhance capacity, seen in Figure 2.21.

Another research based on FFR is shown in [16]. Femto cell is assigned to use sub-bands which are not used in macro cell sub-area to avoid downlink interference between macro cell and femto cell. In the proposed scheme, the macro cell coverage is divided into centre zone and edge region which each region include three sectors, seen in Figure 2.22.

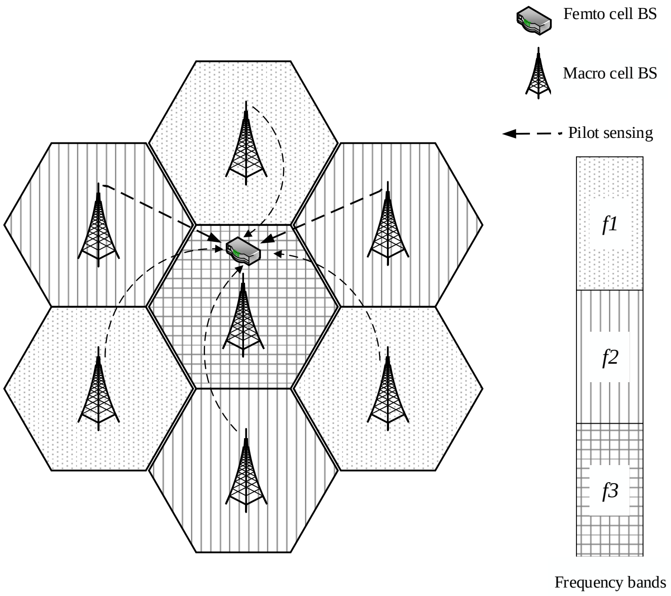

Figure 2.21 Scheme using FFR with pilot sensing

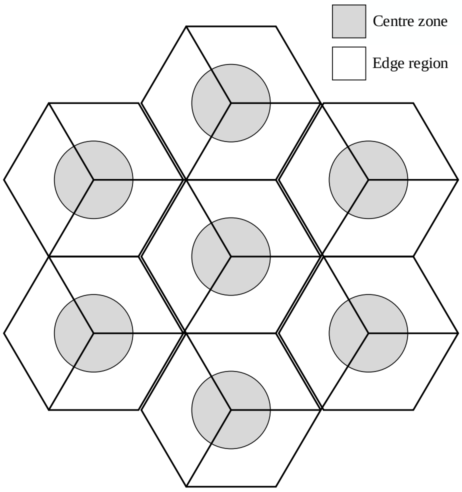

Figure 2.22 Macro cell coverage is divided into center zone and edge region

2.6.5 Cognitive approach

In [17], they proposed a cognitive-based by sharing path loss information and component carriers (CC) usage information among neighboring femto cells to improve efficiently downlink interference between femto cell base stations. Each femto cell base station evaluates interference depended on path loss information and

CCs information by neighbors when it is turned on. Then femto cell base station accesses the spectrum intelligently. The process is each femto cell base station selecting CC which is not used by the nearby neighbor.

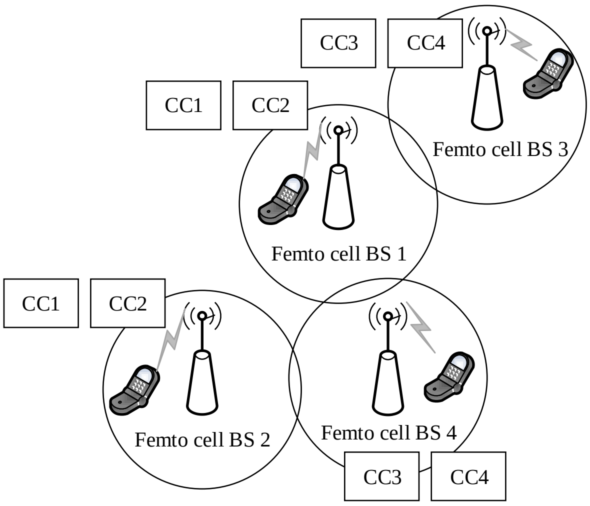

Figure 2.23 Cognitive approach

2.6.6 Power control approach

This method is decreasing transmission power of femto cells to reduce interference between femto cells and macro cell. If transmission power is too high assigned to some femto cells, it will interfere with neighboring femto cells and macro cell. Consequently, we have to control levels of transmission power. Furthermore, both of femto cell and macro cell can use the entire bandwidth with interference coordination that is favorable of this method.

There are many techniques under different conditions that are used in power control approach [21]-[23]. We will show some researches i.e. in [18], they propose an opportunistic power control algorithm based on active femto cells in a cluster in uplink transmission and propose two sensing algorithm such as centralized and distributed. In centralized sensing algorithm, seen in Figure 2.24, macro cell base station estimates the number of active femto cells in a cluster from receiving aggregated interference and assigns the interference allowance information to femto cells for their initial transmission power. On the other hand, in the distributed sensing algorithm, some of femto cells create a new cluster and each femto cell senses that the other femto cells are active in the same cluster. Then, femto cell adjusts its initial transmission power by interference allowance information.

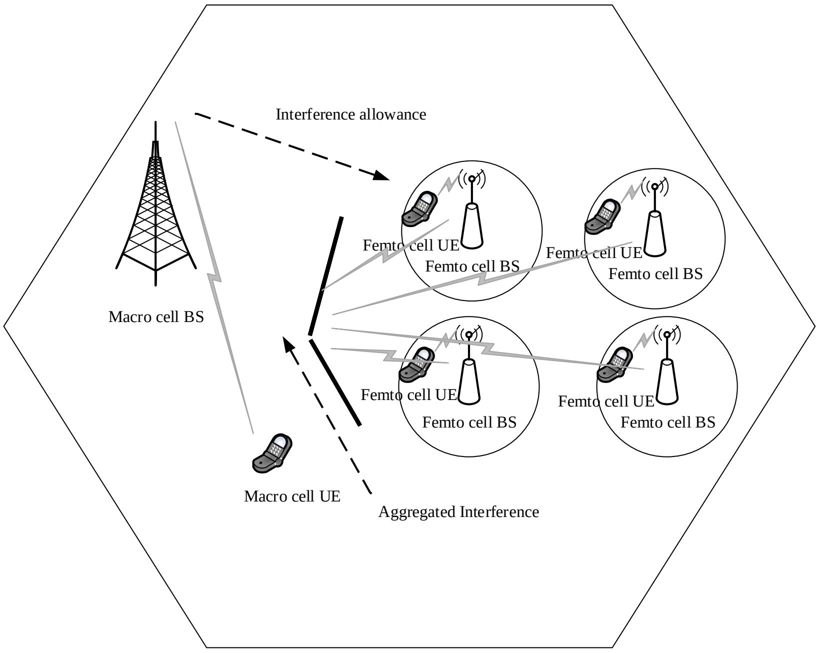

Figure 2.24 Centralize sensing algorithm

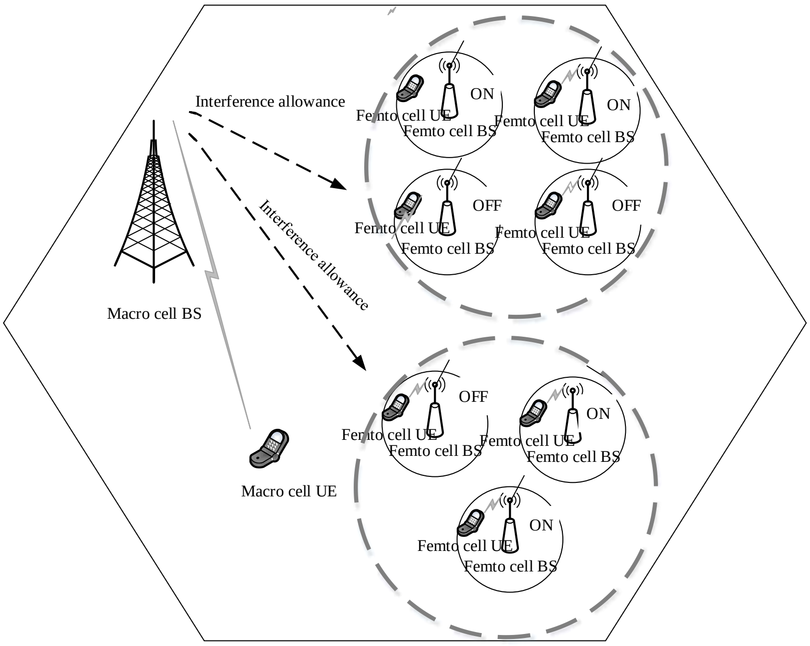

Figure 2.25 Distributed sensing algorithm

Game theoretic models are used to control distributed power as in [19]. The network consists of macro cells and femto cells which are considered downlink power allocation problem; moreover, the aim of each station is maximum its capacity under power constraints. The problem is formulated as a Stackelberg game which is a non-cooperative game. In this game, the macro cell users and femto cell users are assigned as a group of leaders and a group of followers, respectively. Each player not only competes against the other group, but also competes with other players of their own group. Stackelberg equilibrium is the solution of a game.

In [20], they research a suite of distributed power control algorithm with active link protection in macro cell and femto cell networks. Macro cell UE collects the pilot signal power from femto cell base stations to perceive nearby femto cells. Then macro cell UE chooses an access channel and after that initializes the protection margin of the signal. Finally, macro cell UE and femto cell UEs update their transmitted power synchronously by the modified distributed power control based on active link protection algorithm to maintain quality of services.

As above mentioned strategies for improvement, we can combine some techniques with these strategies to mitigate interference and improve performances i.e. [24], they propose a suboptimal algorithm joining power control with scheduling policy. In [25], they use power control approach and cognitive approach to alleviate downlink interference from femto cell base stations to nearby macro cell users. Consequently, we can use any strategies to consider and solve the problems.

2.7 Future Radio Access Technology

The fifth generation systems (5G) are the next innovation for wireless communication. These systems emphasize on the evolution to support the expansion and enhancement of mobile internet and Internet of Things (IoT); moreover, they will become the primary method of network access for person-to-person and person-to-machine connectivity. Everything will be connected by wireless to capacitate to monitor and collect of information and control of devices, such as connected cars, connected homes, moving robots and sensors. In addition, more extensive and richer content will be delivered in real time and with safety, for example high resolution video streaming, tactile internet, media rich social network services, augmented reality, and road safety.

5G systems are expected to support as follow; these systems have to be able to handle traffic volumes of tremendous orders. Higher capacity is regarded as the most significant and challenging requirement for future networks. Then, a hundred times higher data has to be provided in there systems for user experience, furthermore, 5G has to provide ultra-low latency across the access link, cost reduction, ultra-low energy consumption , and allow massive number of devices to be connected simultaneously, cost reduction, and ultra-low energy consumption [26].

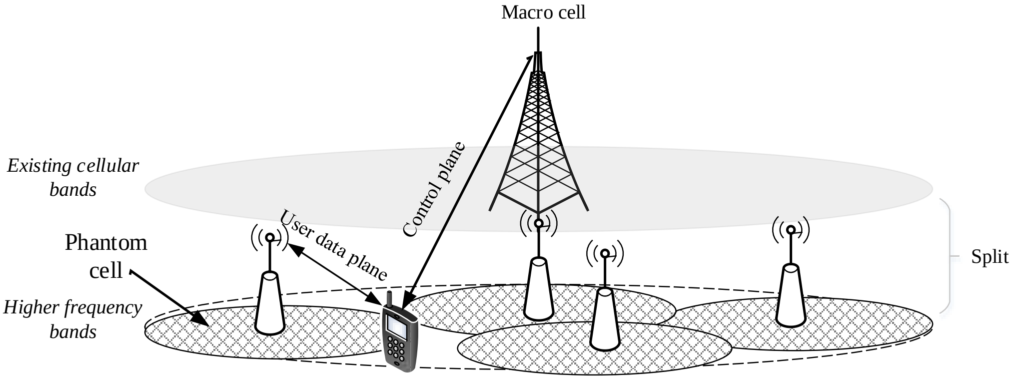

Figure 2.26 Phantom cell concept

In order to support the requirements, 5G concept has changed from previous cellular concept to be a heterogeneous network which cooperates between lower frequency and higher frequency network. Consequently, this structure has two layers that consist of a coverage layer and a capacity layer. Lower frequency bands, which already exit, are used to provide basic coverage and mobility in the coverage layer. The capacity layer uses new higher frequency bands to provide high data rate transmission. The key radio access technologies to exploit higher frequency bands is numerology and waveform design and use of massive MIMO (multiple input multiple output). Moreover, this systems use Phantom cell concept and flexible duplex to integrate of lower and higher frequency bands in this 5G concept. The concept of Phantom cell is based on a multi-layer network which splits the control plane and the user data plane between macro cell and small cells using different bands as shown in Figure 2.26 [27].

Moreover, the spectral utilization can be further enhanced by future radio access technology, namely, Non-orthogonal multiple access (NOMA). NOMA is an intra-cell multiuser multiplexing and introduced via power domain user multiplexing either in time, frequency or code domains. Based on its principal, each users are assigned different power level with the same spectrum rely on their position. Then, on the receiver side, the successive interference cancellation (SIC) method is deployed to cancel stronger interferences as shown in Figure 2.27. This is called power multiplexing technique. Additionally, NOMA performs user multiplexing without depending on the knowledge of the transmitter of the immediate channel state information of each user [28]. Consequently, we will analyze uplink spectral efficiency in NOMA via channel model of Rayleigh and Nakagami fading in chapter 5.

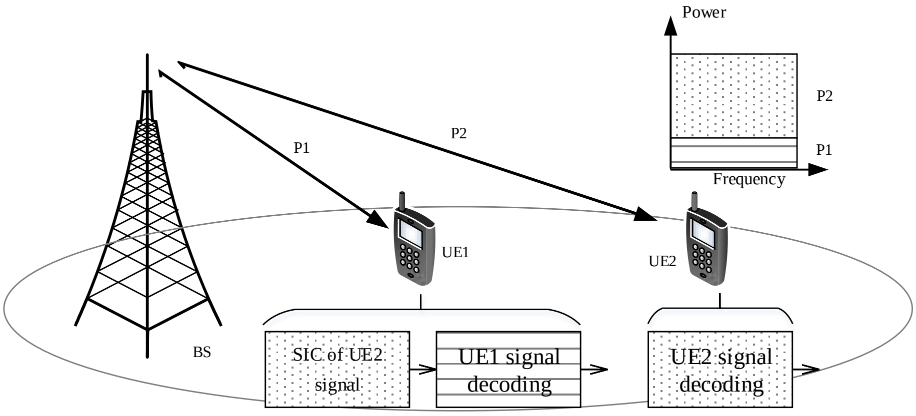

Figure 2.27 Basic NOMA using SIC for receiver side.

5G is the next evolution of mobile communication and will be a significant factor of the networked society. The capability of 5G systems must be promise technology because they can connect for a wide range of applications and use cases including higher data rates, massive connectivity, very low latency and ultra-high reliability.

CHAPTER III

OPTIMAL RATE SCHEDULING FOR UPLINK CDMA

3.1 Media Access Strategies

From the past to the present, the main challenge of cellular networks is resources (i.e. frequencies) limitation to support a number of subscribers for integrated voice and data services; consequently, there are three techniques of media access control to allocate frequencies for services – i.e. FDMA (Frequency Division Multiple Access), TDMA (Time Division Multiple Access) and CDMA (Code Division Multiple Access). In FDMA, this technology allows a couple of user use only one frequency all the time of communication for each other but it is not efficient for employment resources. Then TDMA technology services subscribers on the different time slots but the same frequency thus this technique is more useful than FDMA. The CDMA technology, which allows all users to transmit their information at the same time and same frequency by coding, is more advantageous than FDMA and TDMA as follows;

Firstly, from Figure 3.1, we notice that each user in CDMA employ less power than other techniques in the same power level. Secondly, CDMA differs from both FDMA and TDMA in term of capacity [29]. FDMA and TDMA are known as hard capacity systems that can serve users at fixed numbers. On the other hand, infinite number of users can be provided by CDMA which is known as soft capacity, regardless the quality of transmission. Finally, CDMA is also suitable for transmitting human speech or burst data [30], which consists of active and inactive period. During inactive mode, transmitters could turn down their power in order to save battery and reduce interference to the neighbors.

Practically, the second generation transmit integrated voice and data services, all voice and data are transmitted in the order to arrival time; on the other hand, voice and data services are separately transmitted by circuit and packet switching technology in the third generation systems [51]. Accordingly, we propose scheduling between voice and data traffics and dynamically adapt rate of transmission under power minimization constraint for uplink CDMA which differs from the conventional CDMA systems that combine voice and data traffic, and transmit them. This leads the delay of voice service that is more when increasing data service in conventional CDMA. Our protocol uses priority of voice more than data because voice service need real time to communicate; voice and data are kept in separate queues; each queue is arranged in the order to arrival time. Moreover, we consider reducing maximum transmission time of data service by fare share concept and discuss more in the next section.

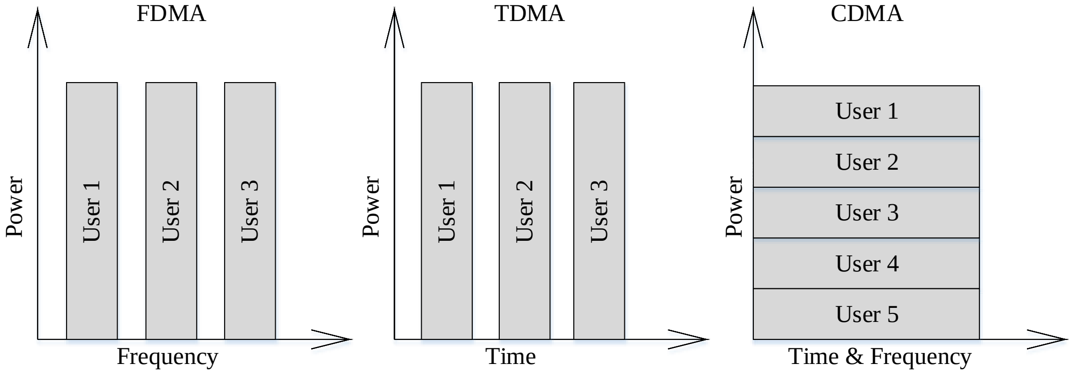

Figure 3.1 FDMA TDMA and CDMA system

This chapter is organized as follow. We describe the CDMA system model in section 3.2 and propose scheduling between voice and data traffics and dynamically adapt rate of transmission under power minimization constraint in section 3.3. The simulation parameters and results are shown in section 3.4 and 3.5, respectively. Finally, we conclude this chapter in section 3.6

3.2 CDMA System Model

CDMA, which is used in third generation of wireless communications, allows all users to transmit their information at the same time and same frequency. Each user’s signal is separated from one another by different orthogonal codes because a signal of one user interferes the others. It means that the capacity and quality in CDMA system relates to interferences [30]. Meanwhile, quality of the CDMA is mentioned to the probability of bit error or Bit Error Rate (BER). It is well known that BER can be written in a function of energy per bit per noise power density (E_b / N_o) [31]. Consequently, we can write CDMA system model in term of E_b / N_o as follows that the average modulating signal power per bit is equal to

$$E_b = ST \tag{3.1}$$

where S is the average modulating signal power and T is the bit duration. We substitute the bit rate which $R = 1/T$ to rewrite the equation (1) as

$$\frac{E_b}{N_o} = \frac{S}{R \cdot N_o} \tag{3.2}$$

Then, we replace $N_o = \overset{o}{N}/W$ in the equation (3.2) where N is the total noise and W is the system bandwidth. So we get as follows:

$$\frac{E_b}{N_o} = \frac{S}{\overset{o}{N}} \cdot \frac{W}{R} \tag{3.3}$$

The ratio W / R is called as spreading or processing gain and the ratio $S / \overset{o}{N}$ is signal-to-interference-plus-noise ratio (*SINR*).

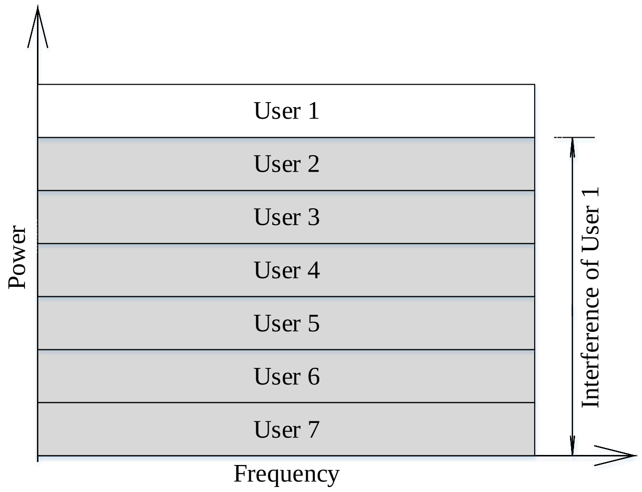

Figure 3.2 Demonstration of signal and interference in CDMA system

In this chapter, we focus on uplink or operation from mobile to base station in the single-cell environment because the capacity of CDMA system is often limited. Figure 3.2 shows a good demonstration of signal and interferences in the

CDMA system [30]. In the system, the total interference in the frequency band is equal to sum of power from other users. Then, $S/\overset{o}{N}$ follows the equation (3.4);

$$\frac{S}{\overset{o}{N}} = \frac{1}{K-1} \tag{3.4}$$

where K is the total number of users in the system. For example, in this case K = 7, the sum of power of user number 2 to 7 is the interference of the user number 1; then *SINR* of any one user is $S/\overset{o}{N} = 1/6$ as each user is the same power level (perfect power control).

In [32] they generalize the total interference which consists of interfering power from the other users and back ground noise in the equation (3.5)

$$\overset{o}{N} = \sum_{j=1, j \neq i}^{K} h_j P_j + \eta_o W \tag{3.5}$$

where h_j and P_j are the channel gain and transmitted power of user *j*; *K* is the number of total users in the system and η_o is the background noise. Accordingly, we can rewrite E_b / N_o of user *I* in the general form as

$$\left(\frac{E_b}{N_o}\right)_i = \left(\frac{h_i P_i}{\sum_{j=1, j \neq i}^{K} h_j P_j + \eta_o W}\right) \cdot \frac{W}{R_i} \tag{3.6}$$

where R_i is the transmission of the user *i*. Normally E_b / N_o, symbolize as γ, is a predetermined value based on the traffic requirement.

From the equation (3.6), power and rate transmission can be varied in order to achieve the required γ. It means that we can find the optimal values both power and rate to guarantee γ.

After that, we focus on the minimization of total transmitted power which is subject to acceptable E_b / N_o (using the equation above), power and rate constraints.

$$\min \sum_{i=1}^{K} P_i \tag{3.7}$$

Subject to

$$\gamma_i \le \left(\frac{h_i P_i}{\sum_{j=1, j\ne i}^{K} h_j P_j + \eta_o W} \right) \cdot \frac{W}{R_i} \tag{3.8}$$

and

$$0 < P_i \le P_{i_{\max}}, r_i \le R_i \tag{3.9}$$

From (3.8) condition, we reduce it to simpler form [33].

$$\frac{W}{r_i \gamma_i} \cdot h_i P_i \ge \sum_{j=1, j\ne i}^{K} h_j P_j + \eta_o W \tag{3.10}$$

Then, we add $h_i P_i$ at the both sides of the inequality in (3.10).

$$h_i P_i \ge \frac{\sum_{j=1}^{K} h_j P_j + \eta_o W}{1 + \frac{W}{r_i \gamma_i}} \tag{3.11}$$

From the equation (3.11), we sum up all users.

$$\sum_{j=1}^{K} h_j P_j \ge \eta_o W \left(\frac{\sum_{j=1}^{K} \frac{1}{(1 + \frac{W}{r_j \gamma_j})}}{1 - \sum_{j=1}^{K} \frac{1}{(1 + \frac{W}{r_j \gamma_j})}} \right) \tag{3.12}$$

Then, we substitute $\sum_{j=1}^{K} h_j P_j$ in (3.12) into the equation (3.11).

$$\sum_{j=1}^{K} \frac{1}{(1 + \frac{W}{r_j \gamma_j})} \le 1 - \frac{\eta_o W}{h_i P_{i_{\max}} (1 + \frac{W}{r_j \gamma_j})} \tag{3.13}$$

From [33], [34], they define $1/(1 + W / r_j \gamma_j)$ as power portion of user *i* or power index Δ_i.

As a result, rate and acceptable γ have to satisfy the condition in (3.13), after that, we assume that $P_{i_{\max}}$ is no limit of power transmission (∞) for simplicity. The condition is reduced to

$$\sum_{j=1}^{K} \frac{1}{(1+\frac{W}{r_j \gamma_j})} \le 1 \tag{3.14}$$

Our idea is to use the concept of power minimization above with the proposed rate adaptation and scheduling technique to serve voice and data traffics effectively.

3.3 Our Proposed Technique

To scheduling voice and data traffic efficiently, our concept is to allocate the resource that leftover from voice assignment to data traffic. From the equation (3.14), we have

$$\sum_{i=1}^{K_v} \frac{1}{(1+\frac{W}{r_{v_i} \gamma_v})} + \sum_{j=1}^{K_d} \frac{1}{(1+\frac{W}{r_{d_j} \gamma_d})} \le 1 \tag{3.15}$$

Define $\sum_{i=1}^{K_v} 1/(1+W/r_{v_i}\gamma_v)$ and $\sum_{j=1}^{K_d} 1/(1+W/r_{d_j}\gamma_d)$ as power portion of voice (Δ_v) and data traffic (Δ_d). γ_v and γ_d are the required energy per bit per noise power density of voice and data traffics, respectively. r_{v_i} is the transmission rate of voice traffic and r_{d_i} is data transmission rate which varies on message length. Our scheduling is different from conventional CDMA in Figure 3.3. The left-hand side, all new entries (voice and data traffics) are sorted and assigned the resource in the order to arrival time in conventional, whereas the right-hand is our proposed protocol, voice and data are separated in voice and data queues, respectively.

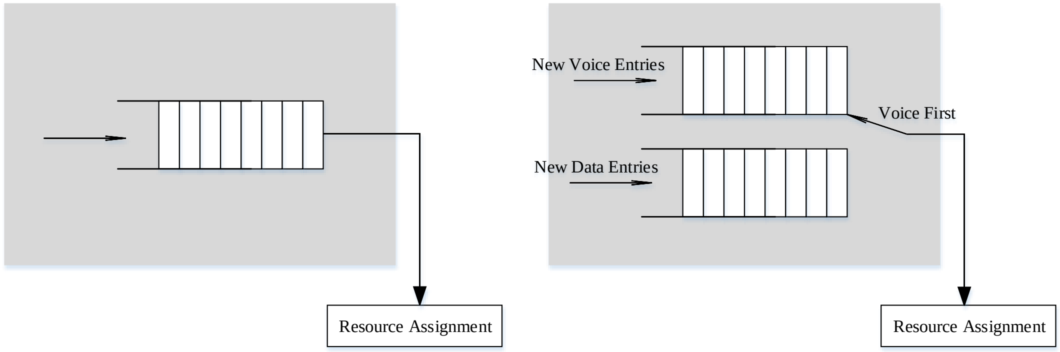

Figure 3.3 Comparison between two CDMA systems, with and without priority

To maximize the capacity, we change the inequality in the equation above to be equality. In practically, we use priority of voice more than data traffic so the resource that leftover from voice assignment is allocated to data traffic. Then, the resource allocation for data traffic is shown as below;

$$\sum_{j=1}^{K_d} \frac{1}{(1+\frac{W}{r_{d_j}\gamma_d})} = 1 - \sum_{i=1}^{K_v} \frac{1}{(1+\frac{W}{r_{v_i}\gamma_v})} \tag{3.16}$$

If no resource remains in the system, incoming data requests will be sequentially blocked. The blocked users are forced to wait until the resource becomes available. In this status, the data users communicate with base station by sending only synchronization information with rate, $r_{syn} = 1.2\,\text{kbps}$[35].

Among data traffic is various based on their message lengths. For example, a user with longer message length is assigned power portion more than another with shorter message. It means that longer message's users can transmit their information with higher rate than the shorter. This strategy is to keep the maximum transmission time minimize. According to [34], the optimal solution to minimize the maximum transmission time following the condition;

$$\frac{L_1}{r_1} = \frac{L_2}{r_2} = \ldots = \frac{L_{K_d}}{r_{K_d}} \tag{3.17}$$

where L_i is the length of message of user *i*. This idea is the same as max-min fare share in [36] which allocates resource based on users' demand.

Our strategy is to assign rate to each user varied on their message length from the resource left from voice allocation. Firstly, we calculate the average rate (r_{avg}) of all data users from the remaining resource as

$$r_{avg} = \frac{W}{\gamma_d} \cdot \frac{1}{(\frac{K_d}{(1-\Delta_v)} - 1)}. \tag{3.18}$$

Secondly, we arrange data users in the order of message length;

$$L_1 > L_2 > ... > L_M > L_{M+1} > ... > L_{K_d} \tag{3.19}$$

where L_1 is the longest message length, L_M is the middle length and L_{K_d} is the shortest length. Finally, the transmission rate of user *i* is calculated from

$$r_i = normalise(L_i / L_M) \times r_{avg}. \tag{3.20}$$

Our rate assignment techniques for data traffic is different from LGT (Long based group-wise transmission) in [34] which data users are divided into only two groups, i.e. longer message and shorter message and easier to implement to the real CDMA system.

Our fair share concept is different from [8] because we use middle value of resource requirement to calculate the assigned resource to each user instead of minimum value. Moreover our scheme is easier to implement to the real CDMA system

3.4 Simulation Parameters

We use the parameters of IS-95 CDMA based system to test our proposed idea. The total bandwidth (*W*) is 1.25 MHz. Voice traffic rate is 9.6 kbps in the set 1 of IS-95 specifications [30] and the generation of voice traffic is categorized into 2 states, i.e. talk spurt and silence. Information is transmitted at 9.6 kbps in talk spurt period whereas synchronization bits are sent at 1.2 kbps in silence period [35]. The averages of talk spurt and silence period are 1 and 1.35 sec and the maximum tolerable delay is 32 msec [36]. The minimum acceptable E_b / N_o of voice traffic, γ_v, is 7 dB

Meanwhile, data traffic, the message arrival is Poisson process at multiple rates and various message lengths. The minimum data rate is 1.8 kbps in the set 2 and the maximum rate is 115.2 kbps. The synchronization rate is the same as voice rate and the minimum acceptable E_b / N_o of data traffic, γ_d, is 10 dB

Base station monitors their service users every 1.25 msec to check the statues of users that active or inactive and to allocate the resource to the active users. However, the inactive users transmit only synchronization rate to the base station.

Inactive users have to keep synchronize with the base station for all the time so some resources are wasted for synchronization reason as below;

$$\frac{k_v}{1+\frac{W}{r_{syn}\gamma_v}}+\frac{k_d}{1+\frac{W}{r_{syn}\gamma_d}} \tag{3.21}$$

where r_{syn} is the synchronization rate equal to 1.2 kbps, k_v and k_d are the number of inactive voice and data users in the system.

3.5 Results and Discussions

We categorize our experiments into voice experiment, data experiment and integrated voice and data experiment.

Firstly, voice experiment, in Figure 3.4, we set voice traffic occupying the total capacity 50 percent. After that, we gradually increase the data user into the system. From the result in the figure, the percentage of voice blocking of our protocol is very close to No Data line which means there is no active data user in the system. It implies that the base station assigns the resource to voice traffic firstly. Consequently, it concludes that the volume of data load is not important to the quality of voice service in our protocol.

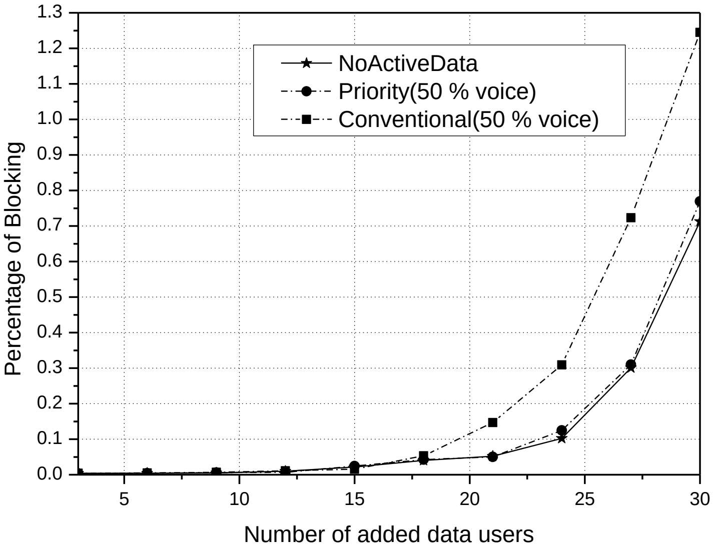

Figure 3.4 Percentage of voice blocking at fixed voice load 50 percent of all capacity

Secondly, data experiment, in Figure 3.5, the variance of our protocol (MultiRates line) become smaller not only in every message length but also in every load condition than LGT protocol. As a result, our protocol provides users with multiple rated based on message lengths; on the other hands, the LGT protocol in [6] assigns only two different rates for various message lengths.

Finally, integrated voice and data experiment, in Figure 3.6, the delay of our protocol increases rapidly when we add the voice users into the system and becomes worse at more than 30 voice users. This effect causes from our scheduling technique that allocates resource to voice firstly. So, in our protocol, the increasing voice users impinge on quality to serve data traffic. From the graph fixed rate at 57.6 and 28.8 kbps, delay of fixed rate 57.6 kbps becomes higher than 28.8 kbps. It is against our understanding in which high rate should deliver shorter transmission time. By the way, it can be explained as follows. High rate transmission urges users to send their information and, at the same time, causes longer waiting queue for transmission. Accordingly, the overall delay becomes longer than usual.

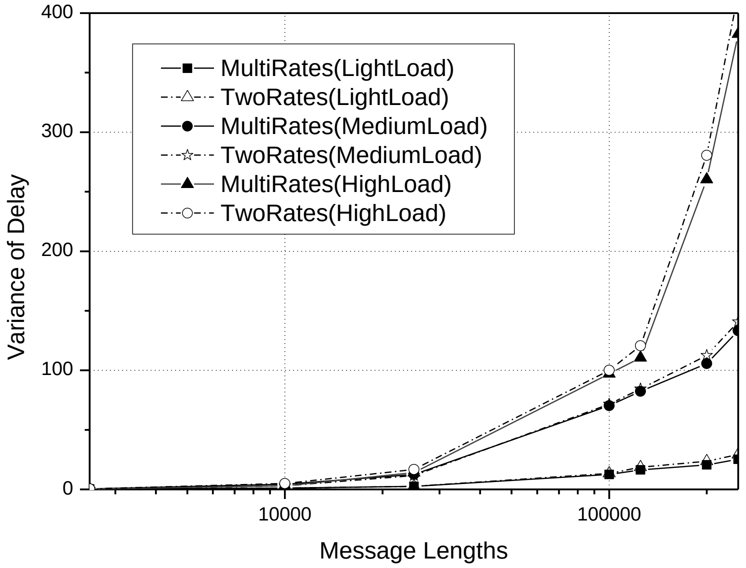

Figure 3.5 Variance of delay between our protocol and the LGT protocol

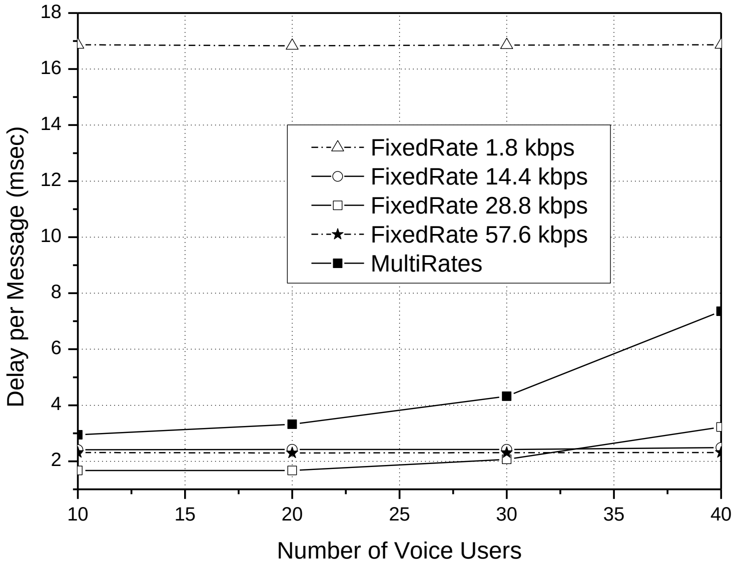

Figure 3.6 Delay per message at 40 data users

3.6 Conclusion

We propose the cross layer protocol on CDMA system for integrated voice and data traffics. From the results, our protocol serves voice traffic more efficiently than the conventional CDMA because we guarantee the voice quality by allocating the resource to its transmission firstly. Nonetheless, the data delay of our protocol become worse than the conventional due to the waiting time for voice assignment. Additionally, we present the rate adaption technique based on power minimization constraint and fare share concept. This scheme is not only to suit to a variety of loads and traffic conditions but also to minimize the maximum transmission delay.

CHAPTER IV

NEW RATE OPTIMIZATION FOR FEMTO CELLS

4.1 Motivation

Recently, subscribers demand higher data rates for supporting their applications in mobile communication. However, environments in this present are numerous building and skyscrapers, particularly in metropolitan, that causes coverage's problem or we called dead spot, especially indoor users. This problem can be improved by many manners; however, femto cell seems to be the best way.

Deploying femto cell network makes the transmitters and receivers closer together. Furthermore, femto cells are low-cost, low-power, short-coverage range, small, simple deployment and high-bandwidth service [37]. Figure 4.1 shows the scenario of using femto cell, several femto cells are located in the area which is covered by the macro cell. Each femto cell has its own base station to serve its users. Femto cells operate the same licensed spectrum as macro cell due to resources limitation that we know as co-channel deployment. As a result, one main challenge is management of interference between neighboring femto cells, and between femto cell and macro cell. There are two types of interferences as follow; firstly, co-tier interference is occurred by neighboring femto cells. Then cross-tier interference is happened between femto cell and macro cell.

Many approaches are used to mitigate interference [11]. For example, femto-aware spectrum arrangement in [12], the spectrum is divided in two parts: macro cell and macro cell-femto cell spectrum. Allocation to femto cell is worked by mobile operator but there is disadvantage when increasing number of macro cell users near the femto cell. Fractional frequency reuse method in [16], whole frequency band is allocated to be many sub-bands. Then sub-bands are assigned to zone which area is divided in center zone and edge zones; however, this is insufficient of using bandwidth resource. Power control approach is seemed to be efficient to reduce interference.

Power control method is addressed in many work such as in [19], [38]-[39], which considers power allocation problem in macro cells underlaid with femto cells. Base on theory, increasing transmitted power not only raise data rates, but also increase interference. Furthermore, in [20]-[21], [40], they also optimize power for femto cells by different means and conditions. Then, in [25], they concentrate on data rates of femto cells to support their users that is similar to [34] work. That they propose a new packet rate scheduling by optimization of data rate from packet length so we can find out by various ways. As a result, we have to consider more than one factor to improve the problem, moreover, power and data rate are relative to obvious identity of the quality of services for subscribers. Accordingly, the major challenge is co-tier interference for tradeoff between the number of active femto cells and the signal quality.

In this chapter, optimization of data rates of femto cells is concerned to guarantee their signal quality, constrained by the acceptable SINR. We maximize data rates that relate to transmitted power vary on parameters such as background noise power, bandwidth, number of active femto cells, and interfering power by linear programming and simplify the mathematical to calculate it. The results from simulation can be used to planning femto cells network under macro cell network. In addition, we emphasize data rates because data rates are the easiest parameter that subscribers demand to consume.

This chapter is organized as follow. We describe background knowledge of femto cell in section 4.2 and meaning of optimization in section 4.3. Moreover, we propose rate optimization by using linear programming in section 4.4. The simulation parameters and results are shown in section 4.5. Finally, we conclude this chapter in section 4.6

4.2 System Model

We consider the downlink of femto cell network in Wide-Code Division Multiple Access (WCDMA) system. From Figure 1, there are some femto cells in the existing macro cell network. We concentrate on a femto cell user, acting as victim, receiving the signal from its femto cell base station. Due to spectrum scarcity, other N femto cells, surrounding near the femto cell user as aggressor, use the same spectrum. As a result, the femto cell user is interfered by other N femto cells that situation is called as co-tier interference. We desire to find maximum data rate of each femto cells which can service to clients with the quality of signal.

For this reason, signal-to-interference-plus-noise ratio (SINR) is a parameter which indicates the quality of the system. The SINR of femto cell i can be written as

$$\gamma_{fi} = \frac{W}{R_{fi}} \cdot \frac{P_{fi} \cdot |h_i|^2 \cdot d_i^{-\beta}}{\sum_{j=1, i \neq j}^{N} P_{fj} \cdot |h_j|^2 \cdot d_j^{-\beta} + \eta_0} \tag{4.1}$$

where W denotes the bandwidth of channel; P_{fi} and P_{fj} respectively denote the transmitted power from the femto cell i and other femto cells; d_i denotes the distance between the femto cell user and its femto cell base station; d_j is the distance between the femto cell user and other neighboring femto cells; R_{fi} is the data transmission rate of femto cell i; η_0 is the background noise power; β is the path loss exponent which shapes the channel or environment condition. Normally, $\beta = 2$ means free space as $\beta = 3$ to $\beta = 6$ determine the increasing degrees of obstruction.

There are many ways, that we can solve problems, to optimize femto network such as power and data rate optimization. From [20]-[21], [40], they optimize transmitted power to reduce interference and maintain quality of signals and QoSs (quality of services). In some cases, we focus on yield of clients, so that we solve the problem by data rates optimization. Solution of data rates has many methods to find. For example, in some work (e.g. [25]), they find the maximum of total data rate by indicating transmission power from Lagrangian function whose is very complexity. Finally, from the equation (4.1), we can use it to find data transmission rate optimization in section 4.4.

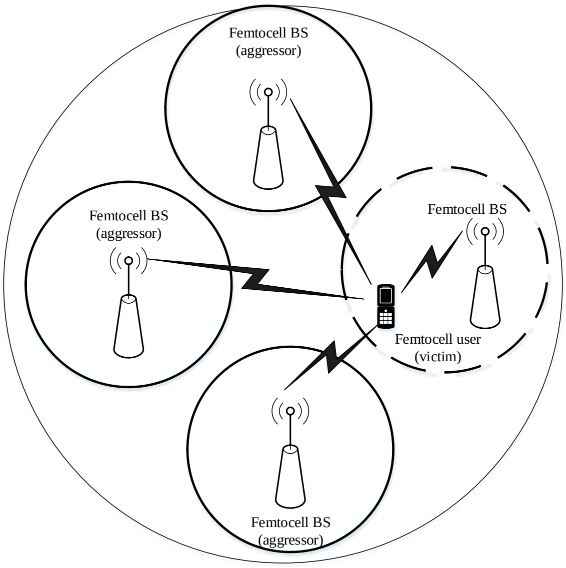

Figure 4.1 Interference in Femto Cell Environment

4.3 Optimization Problem

Nowadays, optimization or mathematical programming is adapted to find the best solution from all possible solutions in many fields as economics, engineering, business, mathematics, research etc and there are many optimization methods. Optimization principle is the process of mathematics and yield in quantity; therefore, problems that are solved in optimization are in term of mathematical model. Generally, purpose of optimization is maximum or minimum of objective function and finding of objective function sometimes have to be determined some constraints. Accordingly, defining of objective function and constraints to find maximum and minimum is significant for optimization [41].

A general formulation of the optimization problem consists of as following;

- **Decision variables** are the values that are unknown in starting problem and display things that we can adjust.
- **Objective function** is a mathematical equation that combines the decision variables to show our propose which we want to maximize or minimize our problem

- **Constraints** are mathematical expressions that combine the decision variables to define limitation of the feasible solutions.
- **Variable bounds** permit on any value from minus infinity to plus infinity.

There are normally two types of optimization problem solution, namely linear programming (LP) and non-linear programming (NLP).

4.3.1 Linear Programming

Linear programming (LP) is the process of solving an optimization problem which objective function and constraints are linear. The constraints may be equalities or inequalities. Linear programming problem can be written in canonical form:

$$\max a^{t}\mathrm{x} \tag{4.2}$$

$$\text{subject to} \qquad A\mathrm{x} \le b \tag{4.3}$$

$$\text{and} \qquad \mathrm{x} \ge 0 \tag{4.4}$$

where x display the vector of unknown decision variables (x=[x_1, x_2, …, x_1]), *a* and *b* are vectors of known coefficients, *A* is a known matrix of coefficients, and $(\_)^{t}$ is the matrix transpose. On the other hand, if we want to minimize problem, we have to multiply by -1 to coefficients of objective function.

In this chapter, we use MATLAB which there are interior-point, active-set, and simplex algorithms to solve linear programming problem. Consequently, we focus on the simplex algorithm, is invented by George Dantzig, because this algorithm is one of the earliest and best known optimization algorithms. The simplex method is an iterative procedure which solves a linear equation in each of its steps and stop when the optimum is found or the solution is infeasible.

The steps of simplex method as follow:

Step 1: Change inequalities to be equations by adding slack and surplus variables. We add slack variable on the left hand side when the inequality constraint has ≤ type. On the other hand, when the inequality constraint has ≥ type, we add surplus variable on the left hand side by subtraction. For example, we have

$$\max \quad z = a_1x_1 + a_2x_2 + a_3x_3 \tag{4.5}$$

$$\text{subject to} \quad A_{11}x_1 + A_{12}x_2 + A_{13}x_3 \le b_1 \tag{4.6}$$

$$A_{21}x_1 + A_{22}x_2 + A_{23}x_3 \le b_2 \tag{4.7}$$

$$A_{31}x_1 + A_{32}x_2 + A_{33}x_3 \le b_3 \tag{4.8}$$

$$\text{and} \quad x_1, x_2, x_3 \ge 0. \tag{4.9}$$

Then, we change inequalities to be equations as follow;

$$\max \quad z - a_1x_1 - a_2x_2 - a_3x_3 = 0 \tag{4.10}$$

$$\text{subject to} \quad A_{11}\mathrm{x}_1 + A_{12}\mathrm{x}_2 + A_{13}\mathrm{x}_3 + \mathrm{x}_4 = b_1 \tag{4.11}$$

$$A_{21}x_1 + A_{22}x_2 + A_{23}x_3 + x_5 = b_2 \tag{4.12}$$

$$A_{31}x_1 + A_{32}x_2 + A_{33}x_3 + x_6 = b_3 \tag{4.13}$$

$$\text{and} \quad x_1, x_2, x_3, x_4, x_5, x_6 \ge 0. \tag{4.14}$$

Step 2: Write the simplex table as follow:

Table 4.1 Coefficient of equations (4.10)-(4.14)

	z	x_1	x_2	x_3	x_4	x_5	x_6	b
z	1	$-a_1$	$-a_2$	$-a_3$	0	0	0	0
x_4	0	A_{11}	A_{12}	A_{13}	1	0	0	b_1
x_5	0	A_{21}	A_{22}	A_{23}	0	1	0	b_2
x_6	0	A_{31}	A_{32}	A_{33}	0	0	1	b_3

Step 3: Select entering variable. We select non-basic variable to be basic variable by choosing the most minus value of coefficient. If coefficient of variable in the objective function equal to 0 or plus coefficient, the optimum is reached and stop doing.

Step 4: Select leaving variable by finding portion of *b* and coefficient of entering variable from step 3. Then, we chose the less portion of basic variable that means it is a leaving variable

Step 5: Change basic variable. We change the position between entering variable and leaving variable by calculation of row operation.

Step 6: Repeat step 3 to 5 until reaching the optimum.

4.3.2 Non-linear Programming

Non-linear programming (NLP) is similar to linear programming but the difference is that non-linear programming formulation composed of at least one nonlinear function of objective function or some or all of the constraints. Nonlinear function means that its exponent of variables is more than 2. Additionally, the constraints may be equalities or inequalities. Non-linear programming problem can be written in canonical form:

$$\max\ f(\mathrm{x}) \tag{4.15}$$

$$\text{subject to} \qquad g_i(\mathrm{x}) \le b_i \qquad \text{for } i = 1, 2, \ldots, m \tag{4.16}$$

$$\text{and} \qquad \mathrm{x} \ge 0 \tag{4.17}$$

where f(x) and g_i(x) are given functions of decision variables.

In case that exponent of our function is not 1, we have to solve optimization problem by NLP. However, there are many drawback of NLP [42] i.e. firstly; NLP is hard to differentiate a local optimum from a global optimum. Methods for solving non linear programs have limited information about the problem but from all of non linear information there is no way to know that there exists a different or better local optimum or how to proceed towards it. This also means that there is no way to easily find where the global optimum is. Secondly, NLP is difficult to satisfy equality constraints. Finding an outcome that satisfies curving and twisting equations is different but even if an outcome is found in some point, the equality constraint may be violated when the algorithm tries to move to another point that has a better value of the objective function. Then, computation of the solution in NLP is infinite. The solver in system may report an optimum, but at best it can check certain conditions to guarantee that the point is a local optimum: it is not able to say that the point is a global optimum. It may also carry on solving the value of the objective function for a long time. After that, there is a huge body of very complex mathematical theory and numerous solution algorithms. Non-linear functions have a wider range of characteristics and behaviors than linear functions so it hard to solve the problem. Finally, using the available non-linear solvers in NLP can be complex because most solvers have a large number of user-settable parameters which control details of how the solver will operate. From this reason, it is hard to know in advance how these setting parameters will affect the solution. Moreover, the more available or constraints be in the problem, the more complex to solving in NLP.

As above mentioned disadvantages of NLP, many mathematical optimizations try to avoid such the non-linear approach. Fortunately, in this work, we formulate our problem in linear manner which can be explained in the next section.

4.4 Our Proposed Technique

In [25], they use complicated nonlinear programming to solve the problem; therefore, we propose a simple but efficient method to optimize the data rates of each femto cells by linear programming. From *SINR* equation above, we increase power that is the result to increase data rate. Nevertheless, increasing power has an impact on neighboring cells which is known as co-tier interference; QoSs are decreased by this reason. Thus, we optimize maximum data rates which the quality is still acceptable. The optimization term can be formulated as:

$$\max \sum_{i=1}^{M} w_i R_{fi} \tag{4.18}$$

$$\text{subject to} \qquad \gamma_{fi} \geq \Gamma_{\min} \tag{4.19}$$

$$\text{and} \qquad R_{fi} \geq 0 \tag{4.20}$$

To each $f(R_{fi}) = \dfrac{\sum_{j=1, i\neq j}^{M} P_{fj} \cdot \left|h_j\right|^2 \cdot d_j^{-\beta} + \eta_0}{W \cdot P_{fi} \cdot \left|h_i\right|^2 \cdot d_i^{-\beta}}$, by i = 1, 2, ..., M. Where $\Gamma_{\min}$ denotes the accepted SINR of femto cells, w_i is index that areas are special, higher index means the area which need higher data rate than the others. From the equation (4.19), we can explain as following;

$$[\mathrm{I}] \cdot \left\lfloor f(R_{fi}) \right\rfloor \geq \Gamma_{\min} \tag{4.21}$$

$$\begin{bmatrix} f(R_{f1}) & 0 & 0 & \ldots & 0 \\ 0 & f(R_{f2}) & 0 & \ldots & 0 \\ 0 & 0 & f(R_{f3}) & \ldots & 0 \\ 0 & 0 & 0 & \ldots & f(R_{fM}) \end{bmatrix} \geq \begin{bmatrix} \Gamma_1 \\ \Gamma_2 \\ \mathrm{M} \\ \Gamma_M \end{bmatrix}. \tag{4.22}$$

Addition, we have condition on P_{fi}, *W*, η_0, β, and *M*, we can vary them to see the corresponding results which are shown in next section.

4.5 Results and Discussions

In this section, numerical results are shown by the computer simulation. Setting the common simulation parameters, the background noise (η_0) is set to 0 and the distance between the femto cell user and other neighboring femto cells (d_j) equals to 10 times of the distance between the femto cell user and its femto cell base station (d_i). Furthermore, index of special areas (w_i) and power gain ($|h_i|^2$) are set to be 1.

In Figure 4.2-4.6, we use $\Gamma_{\min}$ = 30 dB and β = 3. From both figures, we can see each line graph that increasing bandwidth has an impact on the higher data rate of its femto cells. Figure 4.2 shows the variation of data rate of the femto cell while increasing the interfering power (P_{fj}) vary on sizes of bandwidth. With an increasing interfering power until $0.05P_i$, the data rate sharply drops and starts to be saturation point. This result is theoretical by SINR equation which data rate and interfering power are negative exponential and means that the stronger neighboring powers are, the worse serving's system operates.

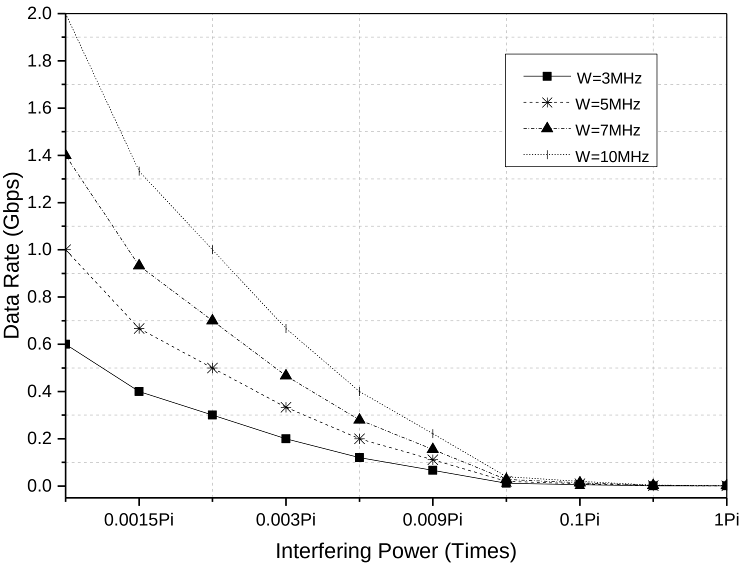

Figure 4.2 Data Rate and Interfering Power; *M* is 5.

Increasing interfering power is the same as adding more neighboring femto cells which we can see in Figure 4.3 that shows the variation of data rate of the femto cell while the number of neighboring femto cells are changed vary on sizes of bandwidth. From the graph, we increase the number of neighboring femto cells; the data rate decreases rapidly in first period and then gradually lessens. This is because the data rate and number of femto cells is theoretical negative exponential by SINR equation. It means that capability of each cells drop by reason of scrambling same frequency of congestion of neighboring femto cells. Moreover, this result can be planning guide to engineers; for example, if we want to increase capacity in the cell which can operate roughly at 4 MHz, from Figure 4.3, we can employ 2, 3, 4, and 5 femto cells which bandwidth is 3, 5, 7, and 10 MHz sequentially to enhance data rate.

Moreover, in Figure 4.4, we change number of neighboring femto cells parameter to be allowance SINR parameter to see variation and trend of the results is similar with Figure 4.3. When we increase SINR constraint which means we want more quality of services to serve subscribers each area but system capacity is less, the data rate exponentially drops.

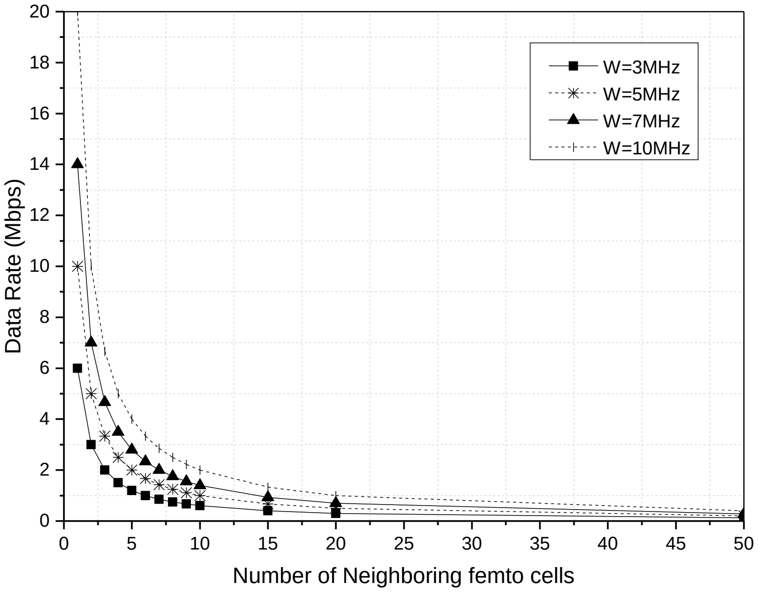

Figure 4.3 Data Rate and Number of Neighboring Femto Cells; P_{fj} is $0.5\,P_{fi}$.

In Figure 4.5, distances to neighboring femto cell are varied to show the difference of data rate of the femto cell vary on some constant bandwidths. From the graph, when we add more distances to neighboring femto cell that means interferences are diminished, data rate exponentially rises. In addition, we increase bandwidth as a result the data rate is higher so we can also see the result in Figure 4.6.

In Figure 4.7, distance between the femto cell user and its femto cell base station is set to constant at 5 meters, d_j equals to $100 d_i$ and the path loss exponent (β) equals to 2. This result shows the variation of spreading gain (*G*) as increasing acceptable SINR vary on background noise power. Then, the spreading gain steadily rises when we increase allowance SINR, seen in the graph, because the spreading gain and allowance SINR are direct variation from the corresponding SINR equation. On the other hands, the spreading gain and the background noise power are opposite, so the each line graph is raised by increasing background noise power. That means spreading gain increases to compensate when the background noise power rises to maintain allowance SINR.

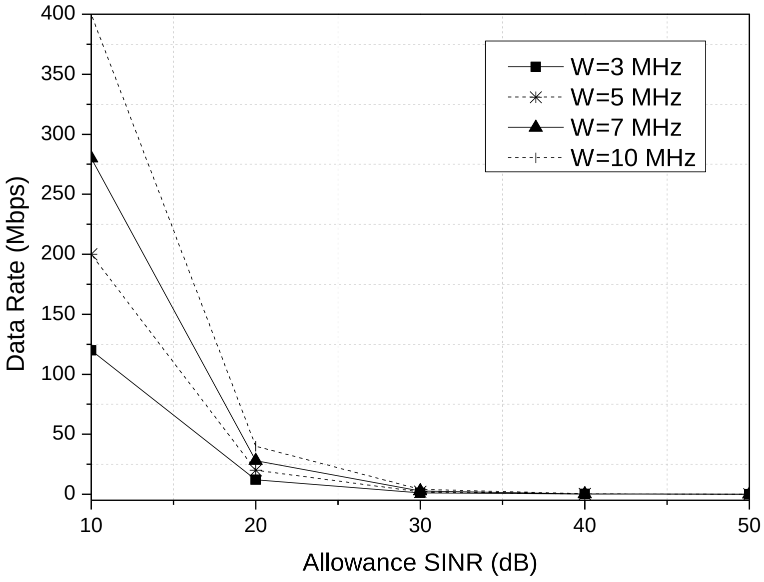

Figure 4.4 Data Rate and Allowance SINR; *M* is 5 and P_{fj} is $0.5 P_{fi}$.

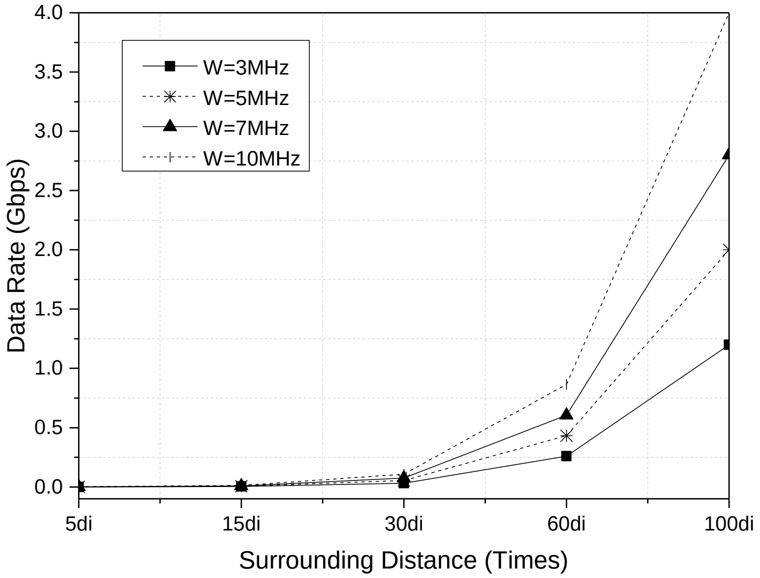

Figure 4.5 Data Rate and Distance to Neighboring femto cell; *M* is 5 and P_{fj} is $0.5\,P_{fi}$.

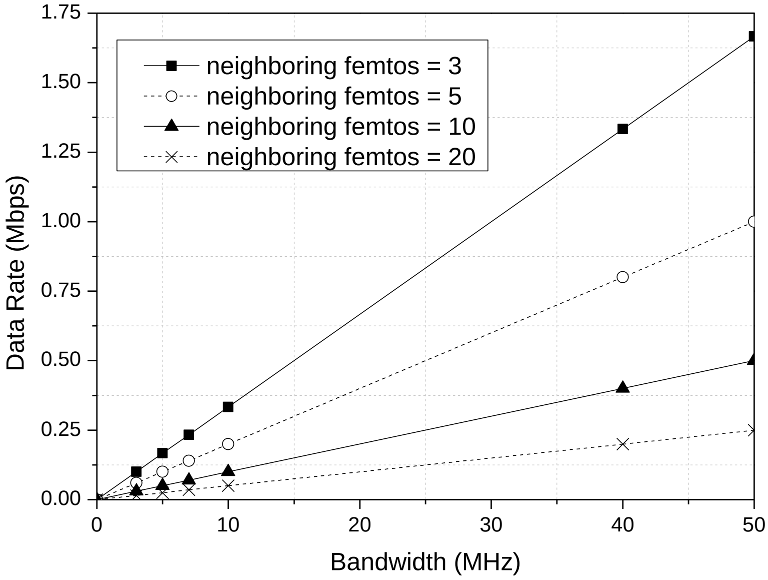

Figure 4.6 Data Rate and Bandwidth (W); P_{fj} equals to $10\,P_{fi}$.

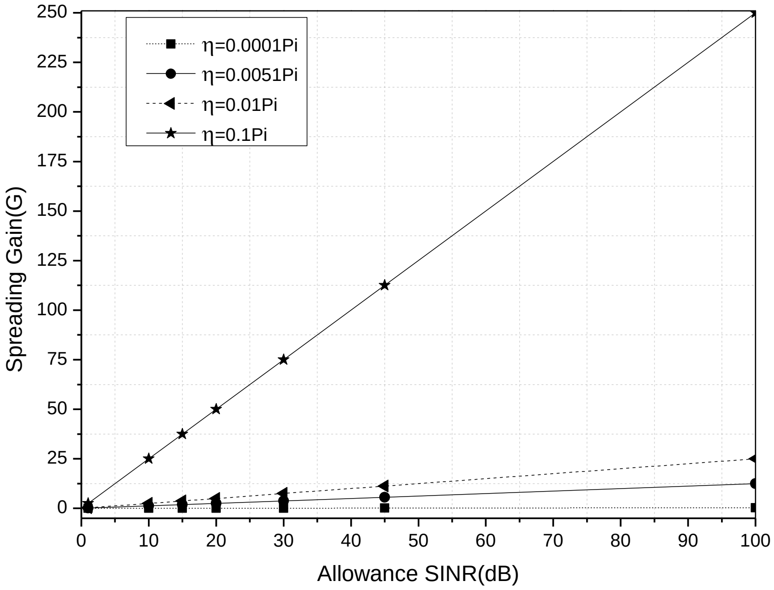

Figure 4.7 Spreading Gain and Allowance SINR; *M* is 5 and P_{fj} is $0.5\,P_{fi}$.

4.6 Conclusion

This chapter focuses on theoretical analysis on operation of femto cell network in the existing macro cell network. The femto cells have to share the same spectrum as their macro cell as a result of the limitation. So the quality of their services to subscribers is worse than usual.

Therefore, we propose to optimize the maximum data rate of each femto cell while the signal quality is still guaranteed under SINR constraint. From the simulation results, the number of neighboring femto cells, interfering power, bandwidth and the background noise power impinge on the data rate of femto cells. Especially, relation between number of surrounding femto cells and data rate can give guide to engineers to plan number of femto cells' operation in macro cell network.

CHAPTER V

THE UPLINK SPECTRAL EFFICIENCY FOR NOMA

5.1 Motivation

From the chapter 2, the new radio access, non-orthogonal multiple access (NOMA), is presented promising. There are many aspects of research challenge, for example, [43]-[44] emphasize on the spectral efficiency estimation in which all parameters are set constantly. Moreover there is more work; the outage probability [45], the rate optimization problem [46], and the maximization problem [47] on the performance of NOMA. However, some random nature parameters in previous work, as mentioned before, are fixed due to simplicity.

Consequently, we focus on evaluation of the uplink spectral efficiency in Rayleigh and Nakagami fading channel whose channel gains and number of users are random variables. Figure 5.1 explains the scenario of uplink transmissions on a cell in 5G cellular network. The base station, known as eNodeB [48], serves its user equipments (UEs). UEs are used all day long in the cell, the serviced area, but UEs are neither in active mode (on) nor in inactive mode (off) at the same time all of UEs because subscribers use their mobile independently. In addition, each UE is able to convey its information through multiple subcarriers and also to share the same resources with one another both in frequency and time domains by multi-carrier scheme and NOMA technique. Hence, the receiver is required SIC process in order to segregate the desired signals from interferences at the receiver side.

Therefore, the signal received at the eNodeB can be shown as

$$S_n = \sum_{i=1}^{N} \sum_{l=1}^{L} P_{i,l} \left| h_{i,l} \right|^2 + \eta_0 \tag{5.1}$$

where N is the total number of UEs in the cell. L is the maximum number of subcarriers to which each UE is allowed. $P_{i,l}$ and $\left| h_{i,l} \right|^2$ are the power and the gain of the signal from UE i on particular subcarrier l. η_0 is the background noise.

In this chapter, we propose the uplink spectral efficiency which the signal gain models in two channel models. Firstly, in Rayleigh channel model, non-line-of-sight fading, it can display urban environment which the path is partially obstructed between transmitters and receivers. So the power gain $\left|h_{i,l}\right|^2$ become an exponential random variable with probability density function

$$f_{\left|h_{i,l}\right|^2}(z) = e^{-z}. \tag{5.2}$$

Secondly, Nakagami channel model, general case, covers both non-line-of-sight (Rayleigh) and line-of-sight (Ricean) cases. So the power gain $\left|h_{i,l}\right|^2$ become a unit-mean gamma random variable with probability density function [31]

$$f_{\left|h_{i,l}\right|^2}(z) = \frac{z^{m-1}}{(m-1)!} m^m e^{-mz} \tag{5.3}$$

where m is Nakagami fading index. When m equals to 1, the probability density function turns to be the exponential as (5.2), Rayleigh pattern. Moreover, the line-of-sight signal will be stronger when m is larger.

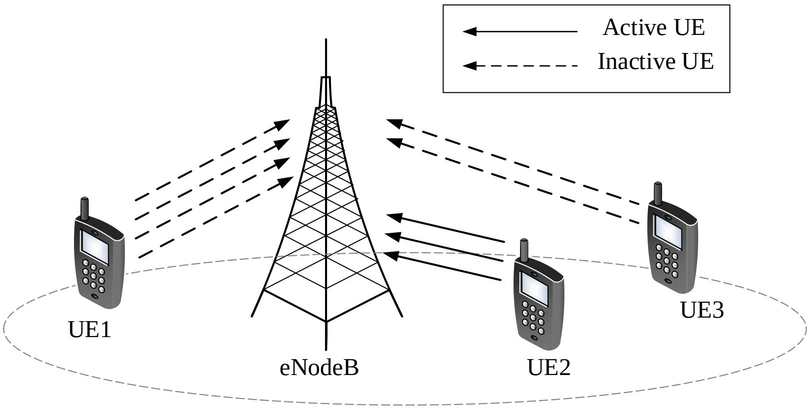

Figure 5.1 Uplink multi-carrier NOMA.

This chapter is organized as follow. We propose a closed form uplink spectral efficiency in Rayleigh and Nakagami fading in section 5.2 and 5.4. Then, in section 5.3 and 5.5 consider random number of UEs in some cases. The numerical results are presented in section 5.6. Finally, we conclude this chapter in section 5.7

5.2 Uplink Spectral Efficiency in Rayleigh Fading

As above mentioned principle of NOMA, we know that NOMA and CDMA are non-orthogonal multiple access scheme, however, there is a difference between them. CDMA employs spread spectrum technology while encoding but NOMA does not. Consequently, the expression of uplink spectral efficiency of individual mobile UE *n* can be defined by the Shannon formula [5], it is similar to CDMA,

$$C_n = \sum_{l=1}^{L} \log_2 \left(1 + \frac{P_{n,l} \left| h_{n,l} \right|^2}{\sum_{i=1, i \neq n}^{N} P_{i,l} \left| h_{i,l} \right|^2 + \eta_0} \right) \quad \text{bps/Hz} \qquad (5.4)$$

where $\sum_{i=1,i\neq n}^{N} P_{i,l} \left| h_{i,l} \right|^2$ is show as the interference of the main signal $P_{n,l} \left| h_{n,l} \right|^2$ on subcarrier *l*.

The power gains on Rayleigh fading environment, $\left| h_{i,l} \right|^2$; i =1, 2, …, N, l =1, 2, …, L, are exponential random variables. Thus the spectral efficiency becomes a function of multi random variables

$$\begin{aligned} C_n &= \sum_{l=1}^{L} \mathrm{E}\left[\log_2 \left(1 + SINR_l\right)\right] \\ &= \sum_{l=1}^{L} \left\{ \int_0^{\infty} \log_2 (1+z) \, f_{SINR_l}(z) dz \right\} \end{aligned} \qquad (5.5)$$

where $SINR_l$ (signal-to-interference-plus-noise ratio of subcarrier *l*) is equal to $P_{n,l} \left| h_{n,l} \right|^2 / (\sum_{i=1,i\neq n}^{N} P_{i,l} \left| h_{i,l} \right|^2 + \eta_0)$. It is quite difficult to find the consequence of (5.5) since the probability density function of SINR, $f_{SINR_l}(z)$, is the function of random value power gains, exponentially distributed. Accordingly, a new efficient method to solve this problem by changing the logarithm base in (5.5) is introduced as

$$C_n = \sum_{l=1}^{L} \left\{ \log_2 e \int_0^{\infty} \Pr(SINR_l > z) \frac{dz}{1+z} \right\} \qquad (5.6)$$

where $f_{SINR_l}(z)dz = d\Pr(SINR_l > z)$ To find the closed form of C_n , based on the probability model of an exponential random variable *X*, when *u* is any constant, is employed,

$$\Pr(X > u) = e^{-u}. \tag{5.7}$$

As mentioned above, we use the probability model in (5.7) due to $\left|h_{n,l}\right|^2$ that is exponentially distributed as well. So we have

$$\Pr(SINR_l > \mathrm{z}) = e^{-\frac{z}{p_{n,l}}(\sum_{i=1,i\neq n}^{N} P_{i,l}\left|h_{i,l}\right|^2+\eta_0)} \tag{5.8}$$

To the next step, we necessarily average the cumulative function $\Pr(SINR_l > z)$ which can be calculated via the moment generating function (MGF) of each $\left|h_{i,l}\right|^2$ [49]. The MGF of any exponential random variable *X*, for a constant *u*, normally is

$$\mathrm{E}\left[e^{-uX}\right] = \frac{1}{1+u} \tag{5.9}$$

Proof (5.9): The moment generating functions of *X* when *X* is an exponential random variable (absolutely continuous random variable) with parameters (λ) is $\mathrm{E}\left[e^{-uX}\right]$ and the probability density function equals to $\lambda e^{-\lambda x}$. Then, we have

$$\begin{aligned}
\mathrm{E}\left[e^{-uX}\right] &= \int_0^\infty e^{-ux}\lambda e^{-\lambda x}dx \\
&= \lambda\int_0^\infty e^{-(\lambda+u)x}dx \\
&= \lambda\left(\left.\frac{e^{-(\lambda+u)x}}{\lambda+u}\right|_0^\infty\right) \\
&= \frac{\lambda}{\lambda+u} \quad \text{, when } \lambda = 1
\end{aligned} \tag{5.10}$$

Consequently, we can get the equation as (5.9).

Then,

$$\mathrm{E}\left[e^{-\frac{z}{p_{n,l}}(\sum_{i=1,i\neq n}^{N} P_{i,l}\left|h_{i,l}\right|^2+\eta_0)}\right] = e^{-\frac{z\eta_0}{P_{n,l}}}\prod_{i=1,i\neq n}^{N}\left(\frac{1}{1+\frac{P_{i,l}}{P_{n,l}}z}\right). \tag{5.11}$$

We replace the MGF found in (5.11) into (5.6). As a consequence, the closed form of uplink spectral efficiency of NOMA without any loss of generality in Rayleigh fading is shown as

$$C_n = \sum_{l=1}^{L} \left\{ \log_2 e \int_0^{\infty} \frac{e^{-\frac{z\eta_0}{P_{n,l}}}}{1+z} \prod_{i=1, i\neq n}^{N} \left(\frac{1}{1+\frac{P_{i,l}}{P_{n,l}} z} \right) dz \right\} \tag{5.12}$$

Assume all N UEs are active at the same time, thus the total spectral efficiency is simply as

$$C_{tot} = NC_n \tag{5.13}$$

However, the number of active UEs is normally random and distributed from 0, 1, 2, …, N. In the next section, the total spectral efficiency in Rayleigh fading is computed when the randomness of the large number of active users is considered in two cases.

5.3 Random Number of Users Equipment in Rayleigh Case

5.3.1 Binomial Random Variable

In the first case, we regard the number of active UEs in term of binomially distributed. The probability mass function of binomial random variable, when the number of active UEs is k, can be define as

$$\Pr(k) = \binom{N}{k} p^k (1-p)^{N-k}, \quad k \in \{0, 1, 2, ..., N\} \tag{5.14}$$

when p denotes as the active probability and $\binom{N}{k} = \frac{N!}{(N-k)!k!}$.

We need to recalculate (5.12) when the number of interfering UEs is random. Recall (5.11) and assume all transmitted uplink powers are identical. Practically, in future radio access, cell size becomes smaller as transmitted power level for each cell is very similar. Consequently, (5.11) becomes

$$\mathrm{E}\left[e^{-\frac{z}{p_{n,l}}(\sum_{i=1,i\neq n}^{N} P_{i,l}\left|h_{i,l}\right|^2+\eta_0)}\right]=e^{-\frac{z\eta_0}{P_{n,l}}}\left(\frac{1}{1+z}\right)^{N-1}. \tag{5.15}$$

Next (5.15) is calculated via the MGF. Let $V(\cdot)$ be any function and the MGF of binomial random variable *Y* with parameters (*N, p*). Then, we have

$$\mathrm{E}\left[V^{Y}(\cdot)\right]=\left[1-p+pV(\cdot)\right]^{N} \tag{5.16}$$

Proof (5.16): The moment generating functions of *Y* is $\mathrm{E}\left[V^{Y}(\cdot)\right]$ and the probability mass function equals to $\binom{N}{y}p^{y}(1-p)^{N-y}$. Then, we have

$$\begin{aligned}\mathrm{E}\left[V^{Y}(\cdot)\right]&=\sum_{y=0}^{N}V(\cdot)^{y}\binom{N}{y}p^{y}(1-p)^{N-y}\\&=\sum_{y=0}^{N}\binom{N}{y}\left(pV(\cdot)\right)^{y}(1-p)^{N-y}.\end{aligned} \tag{5.17}$$

From Binomial theorem:

$$\begin{aligned}(a+b)^{N}&=\binom{N}{0}a^{N}+\binom{N}{1}a^{N-1}b^{1}+\ldots+\binom{N}{N}b^{N}\\&=\sum_{y=0}^{N}\binom{N}{y}a^{y}b^{N-y}.\end{aligned} \tag{5.18}$$

Therefore, we can get the equation as (5.16).

After that we apply (5.16) to (5.15), then the exact average spectral efficiency of UE *n* is

$$C_n=\log_2 e\sum_{l=1}^{L}\left\{\int_0^{\infty}\frac{e^{-\frac{z\eta_0}{P_{n,l}}}}{1+z}\left[1-p+p\left(\frac{1}{1+z}\right)\right]^{N-1}dz\right\} \tag{5.19}$$

As a result, the total spectral efficiency can be represented as

$$C_{tot}=pNC_n \tag{5.20}$$

where *pN* is the expected value of a binomial random variable.

Proof (5.20): The expected value of a binomial random variable can be calculated as follow.

$$\begin{aligned}
\mathrm{E}[Y] &= \sum_{k=0}^{N} k\binom{N}{k} p^k (1-p)^{N-k} \\
&= \sum_{k=1}^{N} k \frac{N!}{(N-k)!k!} p^k (1-p)^{N-k} \\
&= \sum_{k=1}^{N} \frac{N!}{(N-k)!(k-1)!} p^k (1-p)^{N-k} \\
&= pN\sum_{k=1}^{N} \frac{(N-1)!}{(N-k)!(k-1)!} p^{k-1} (1-p)^{N-k}
\end{aligned} \tag{5.21}$$

Given $j = k-1$ so we have

$$\mathrm{E}[Y] = pN\sum_{j=0}^{N-1}\binom{N-1}{j} p^j (1-p)^{((N-1)-j)}. \tag{5.22}$$

Given $m = N-1$ therefore we get

$$\begin{aligned}
\mathrm{E}[Y] &= pN\sum_{j=0}^{m}\binom{m}{j} p^j (1-p)^{(m-j)} \\
&= pN[p+(1-p)]^m \\
&= pN.
\end{aligned} \tag{5.23}$$

5.3.2 Poisson Random Variable

Final case, we consider when the total number of overall active and inactive UEs is unknown; however, several of active UEs is estimated. Let the parameter λ be the average number of active UEs. The probability mass function of Poisson random variable can be define as

$$\Pr(N = k) = \frac{\lambda^k}{k!} e^{-\lambda} \tag{5.24}$$

where k denotes as the number of active UEs at an instance.

Then, (5.15) is calculated via the MGF of Poisson random variable Z with parameters (λ). Then, we have

$$\mathrm{E}\left[V^z(\cdot)\right] = e^{\lambda[V(\cdot)-1]} \tag{5.25}$$

Proof (5.25): The moment generating functions of Z is $\mathrm{E}\left[V^Z(\cdot)\right]$ and the probability mass function (pmf) is $\frac{\lambda^z}{z!} e^{-\lambda}$. Then, we have

$$\begin{aligned} \mathrm{E}\left[V^{Z}(\cdot)\right] &= \sum_{z=0}^{\infty} V(\cdot)^{z} \frac{\lambda^{z}}{z!} e^{-\lambda} \\ &= e^{-\lambda} \sum_{z=0}^{\infty} \frac{\left(V(\cdot)\lambda\right)^{z}}{z!}. \end{aligned} \tag{5.26}$$

when $\sum pmf = 1$:

$$\begin{aligned} \sum_{z=0}^{\infty} \frac{\lambda^{z}}{z!} e^{-\lambda} &= 1 \\ \sum_{z=0}^{\infty} \frac{\lambda^{z}}{z!} &= e^{\lambda}, \end{aligned} \tag{5.27}$$

so we get

$$\begin{aligned} \mathrm{E}\left[V^{Z}(\cdot)\right] &= e^{-\lambda} e^{V(\cdot)\lambda} \\ &= e^{(V(\cdot)-1)\lambda}. \end{aligned} \tag{5.28}$$

After that we apply (5.25) to (5.15), then the exact average spectral efficiency of UE *n* is

$$C_{n} = \log_{2} e \sum_{l=1}^{L} \left\{ \int_{0}^{\infty} \frac{e^{-\frac{z\eta_{0}}{P_{n,l}}}}{1+z} e^{-\lambda\left[1-\frac{1}{1+\lambda}\right]} dz \right\} \tag{5.29}$$

As a result, the total spectral efficiency can be represented as

$$C_{tot} = \lambda C_{n} \tag{5.30}$$

where λ is the average number of active UEs.

5.4 Uplink Spectral Efficiency in Nakagami Fading

In this section, we focus on Nakagami Fading; therefore, the spectral efficiency from the equation (5.4)-(5.5) which $\left|h_{i,l}\right|^{2}$ is a unit-mean gamma random variable can be presented as

$$\begin{aligned} C_n &= \sum_{l=1}^{L} \mathrm{E}\left[\log_2\left(1+SINR_l\right)\right] \\ &= \sum_{l=1}^{L}\left\{\int_0^\infty \log_2(1+z)\, f_{SINR_l}(z)dz\right\} \\ &= \log_2 e \sum_{l=1}^{L}\left\{\int_0^\infty \ln(1+z)\, f_{SINR_l}(z)dz\right\}. \end{aligned} \tag{5.31}$$

To solve this mathematical difficulty, we propose an efficient method to calculate the spectral efficiency by the following.

Let u be a unit-mean gamma random variable so we have a probability density function as

$$f(u) = \frac{u^{m-1}}{(m-1)!} m^m e^{-mu} \tag{5.32}$$

And v is any non-negative random variable and independent from u. $z = u/v$ in which $u = \left|h_{i,l}\right|^2$ and $v = 1/P_{n,l}(\sum_{i=1,i\neq n}^{N} P_{i,l}\left|h_{i,l}\right|^2 + N_0)$, then

$$\mathrm{E}\left[\ln(1+z)|v\right] = \int_0^\infty \frac{1}{z}\left[1-\frac{1}{(1+z)^m}\right]\mathrm{MGF}(mz)dz \tag{5.33}$$

where $\mathrm{MGF}(mz) = \mathrm{E}[\mathrm{e}^{-zmv}]$ is the moment generating function of v.

Proof (5.33): Apply the rules of integration by parts m times,

$$\mathrm{E}\left[\ln\left(1+\frac{u}{v}\right)|v\right] = \int_0^\infty \left\{\frac{1}{(m-1)!}\frac{d^m}{dz^m} z^{m-1}\ln(1+z)\right\} e^{-zmv}dz \tag{5.34}$$

From ([50]; 15.1.3), we have

$$\ln(1+z) = z\,{}_2\mathrm{F}_1(1,1;2;-z). \tag{5.35}$$

where ${}_2\mathrm{F}_1(.,.;.;.)$ is the Gaussian hypergeometric function. Then apply ([50]; 15.2.3) to have

$$\begin{aligned} \frac{1}{(m-1)!}\frac{d^m}{dz^m} z^{m-1}\ln(1+z) &= \frac{1}{(m-1)!}\frac{d^m}{dz^m} z^m\,{}_2\mathrm{F}_1(1,1;2;-z) \\ &= m\,{}_2\mathrm{F}_1(1+m,1;2;-z) \\ &= m\int_0^1 (1+tz)^{-(m+1)}dt \\ &= \frac{1}{z} - \frac{1}{z(1+z)^m} \end{aligned} \tag{5.36}$$

where the third line of (5.36) used ([50]; 15.3.1) . Finally we replace (5.36) into (5.34), as a result, we gain (5.33).

After that, we find $\mathrm{MGF}(mz)$ of v which is

$$\begin{aligned}\mathrm{MGF}(mz) &= \mathrm{E}[\mathrm{e}^{\text{-zmv}}] \\ &= \mathrm{E}\left[e^{-\frac{zm}{p_{n,l}}(\sum_{i=1,i\neq n}^{N} P_{i,l}\left|h_{i,l}\right|^2 + N_0)} \right].\end{aligned} \tag{5.37}$$

From (5.9), the MGF can be solved in a simple form as

$$\mathrm{E}\left[e^{-\frac{zm}{p_{n,l}}(\sum_{i=1,i\neq n}^{N} P_{i,l}\left|h_{i,l}\right|^2 + \eta_0)} \right] = e^{-\frac{zm\eta_0}{P_{n,l}}} \prod_{i=1,i\neq n}^{N} \left(\frac{1}{1+\frac{P_{i,l}}{P_{n,l}} z} \right). \tag{5.38}$$

Therefore, we replace (5.38) into (5.33) and then apply it to (5.31). As a result, the uplink spectral efficiency of NOMA in Nakagami fading is displayed as

$$C_n = \log_2 e \sum_{l=1}^{L} \left\{ \int_0^{\infty} \frac{e^{-\frac{zm\eta_0}{P_{n,l}}}}{z} \left[1 - \frac{1}{(1+z)^m} \right] \prod_{i=1,i\neq n}^{N} \left(\frac{1}{1+\frac{P_{i,l}}{P_{n,l}} z} \right) dz \right\}. \tag{5.39}$$

Assume all N UEs are active at the same time, thus the total spectral efficiency is simply as

$$C_{tot} = NC_n \tag{5.40}$$

However, the number of active UEs is normally random and distributed from 0, 1, 2, …, N. In the next section, the total spectral efficiency in Nakagami fading is calculated when the randomness of the large number of active users is considered in two cases.

5.5 Random Number of Users Equipment in Nakagami Case

5.5.1 Binomial Random Variable

In the first case, we regard the number of active UEs in term of binomially distributed. The probability mass function of binomial random variable is the same as

(5.14). Furthermore, we need to recalculate (5.39) when the number of interfering UEs is random. Recall (5.38) and assume all transmitted uplink powers are identical. Without the loss of generality, (5.38) becomes

$$\begin{aligned} \mathrm{MGF}(mz) &= \mathrm{E}\left[e^{-\frac{zm}{p_{n,l}}\left(\sum_{i=1,i\neq n}^{N} P_{i,l}\left|h_{i,l}\right|^{2}+\eta_0\right)} \right] \\ &= e^{-\frac{zm\eta_0}{P_{n,l}}}\left(\frac{1}{1+z}\right)^{N-1}. \end{aligned} \tag{5.41}$$

Due to calculating (5.41) via the MGF so we apply (5.16) to (5.41). Consequently, the exact average spectral efficiency of UE *n* is

$$C_n = \log_2 e \sum_{l=1}^{L}\left\{ \int_0^\infty \frac{e^{-\frac{zm\eta_0}{P_{n,l}}}}{1+z}\left[1-\frac{1}{(1+z)^m}\right]\cdot\left[1-p+p\left(\frac{1}{1+z}\right)\right]^{N-1} dz \right\}. \tag{5.42}$$

As a result, the total spectral efficiency can be represented as

$$C_{tot} = pNC_n \tag{5.43}$$

where pN ,see the proof in (5.21)-(5.23) is the expected value of a binomial random variable.

5.5.2 Poisson Random Variable

Final case, we consider when the total number of overall active and inactive UEs is unknown; however, several of active UEs is estimated. Let the parameter λ be the average number of active UEs. The probability mass function of Poisson random variable is the same as (5.24) and we do the same step as binomial case to gain (5.41) which are computed through the MGF so we apply (5.25) to (5.41). Consequently, the exact average spectral efficiency of UE *n* in Poisson case is

$$C_n = \log_2 e \sum_{l=1}^{L}\left\{ \int_0^\infty \frac{e^{-\frac{zm\eta_0}{P_{n,l}}}}{1+z} e^{-\lambda\left(1-\frac{1}{1+z}\right)}\left[1-\frac{1}{(1+z)^m}\right] dz \right\} \tag{5.44}$$

As a result, the total spectral efficiency can be represented as

$$C_{tot} = \lambda C_n \tag{5.45}$$

where λ is the average number of active UEs.

5.6 Numerical Results

This section presents the numerical results of the uplink spectral efficiency in Rayleigh fading are calculated from the proposed closed form expression in (5.19) and (5.29) when random variable are respectively binomial and Poisson. Moreover, in Nakagami fading, we compute the spectral efficiency from (5.42) and (5.44) which the number of active UEs are binomial and Poisson random variable as well. Note that signal-to-noise ratio (SNR) is defined as SNR = $P_{n,l} / \eta_0$ in decibel (dB).

5.6.1 Binomial in Rayleigh Fading

The total spectral efficiency in (5.20) is concerned in term of binomial random variable and illustrated by Figure 5.2 – 5.6. The variation between the total spectral efficiency and SNR with different subcarriers to transmit their information is shown in Figure 5.2 and 5.3 but the probability value of value is different. In Figure 5.2, the total number of UEs is $N = 10$ and the probability value of active UEs (*p*) equals 0.03 while using subcarriers to transmit their information of all UEs (*L*) varies from 2, 3, 4 and 5. The total spectral efficiency seems to be exponential increasing; on the other hand, the total spectral efficiency of the graphs in Figure 5.3, using $p = 0.3$, directly proportional increases with the number of employed subcarriers. We vary on the probability value to find which value starts to proportional rise, then we get the probability value of active UEs that equals 0.27.

In Figure 5.4, the total number of UEs is set to 10 and all UEs use 3 subcarriers to convey their information ($L = 3$) in addition the probability value of active UEs (*p*) varies from 0.1, 0.3, 0.5, 0.7 and 0.9. This result displays that high value of active probability activates UEs to transmit their signals and leads to the drop of the total spectral efficiency. Moreover, two lines in the graph from smaller values of the active probability, $p = 0.1$ and 0.3, has changed over high ones, $p = 0.5, 0.7$ and 0.9, which impinge on the increasing interferences of the entire system. It means that the background noise has an effect on transmission system which is slightly interfered, on the other hand the system with more interferences is not meddled by background noise.

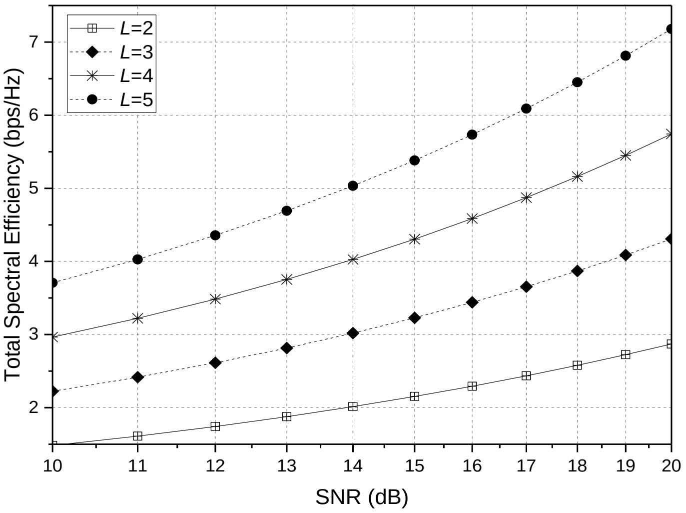

Figure 5.2 Total spectral efficiency and SNR (dB) while vary on *L*; *N* is defined as 10 and probability value of active UEs equals 0.03.

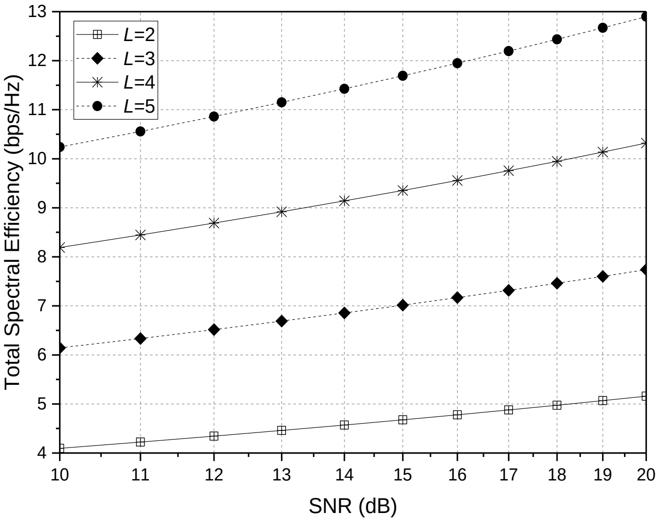

Figure 5.3 Total spectral efficiency and SNR (dB) while vary on *L*; *N* is defined as 10 and probability value of active UEs equals 0.3.

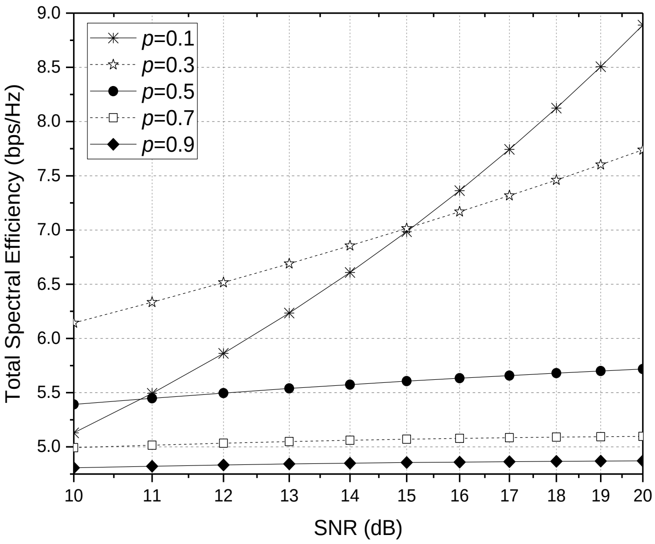

Figure 5.4 Total spectral efficiency and SNR (dB) with various probability value of active UEs (*p*); *N* is defined as 10 and *L* is 3.

Assigning parameters in Figure 5.5, the value of active UEs (*p*) equals 0.3 and all UEs use 3 subcarriers to send their information ($L = 3$) as SNR varies from 10, 13, 15, and 20 dB. This result exposes us the range of optimal total spectral efficiency which is quiet the same in each SNR conditions. When SNR are 10, 13, 15 and 20 dB, we gain the optimal point by the total number of UEs are 7, 6, 5 and 4 in order.

SNR is defined as 10 dB and all UEs use 3 subcarriers to convey their information ($L = 3$) while the total number of UEs (*N*) varies from 5, 7, 15, and 20. The consequence in Figure 5.6 showing the optimal point is similar with Figure 5.5. From the graph, we can get the optimal condition when the total number of UEs in the system equals to 5 while the value of active UEs (*p*) is 0.4. This means the maximum all time active UEs is 2.

5.6.2 Poisson in Rayleigh Fading

The total spectral efficiency in (5.30) is concerned in term of Poisson random variable and expressed by Figure 5.7 – 5.8. The variation between the total spectral efficiency and SNR with various subcarriers to transmit their information. In Figure 5.7, the average number of active UEs (λ) equals 2 while using subcarriers to transmit their information of all UEs (L) varies from 2, 3, 4 and 5. The total spectral efficiency seems to proportionally increase with the number of employed subcarriers.

In Figure 5.8, all UEs use 3 subcarriers to convey their information ($L=3$) and the average number of active UEs (λ) varies from 2, 3, 5 and 10. We can see that larger number of active UEs has an effect on the increasing interferences of the whole system. This leads to reducing the overall spectral efficiency. In addition, the background noise has more influential than there is less interferences.

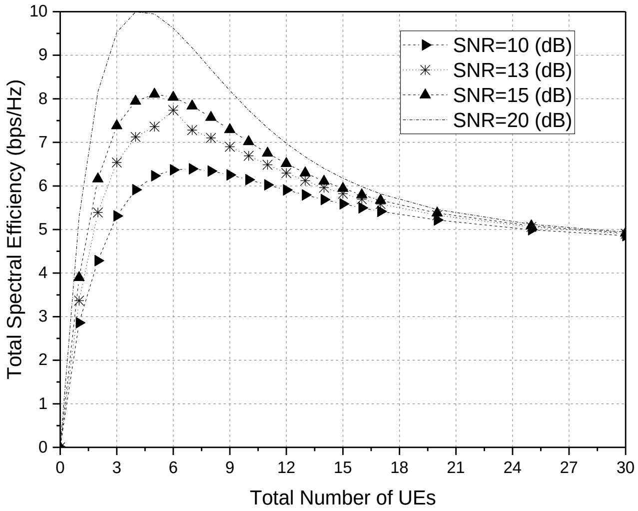

Figure 5.5 Total spectral efficiency and the total number of UEs with various SNR (dB); probability value of active UEs equals 0.3 and L is 3.

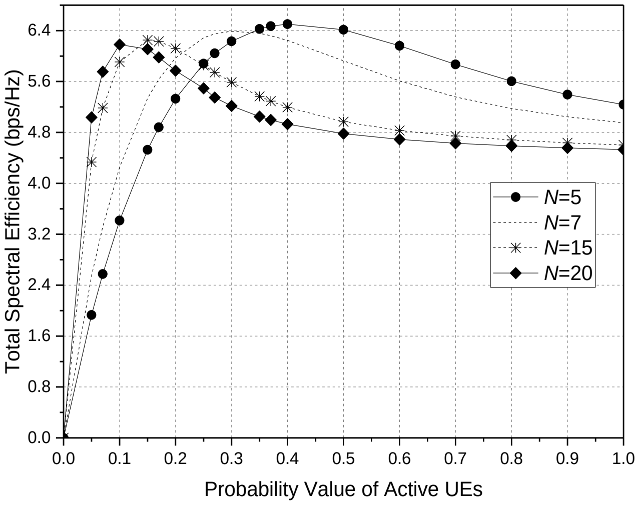

Figure 5.6 Total spectral efficiency and probability value of active UEs with different the total number of UEs; SNR is denoted as 10 dB and L is 3.

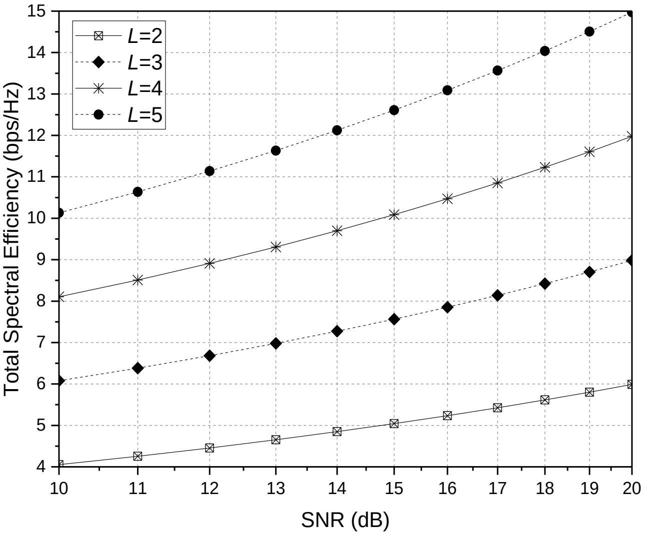

Figure 5.7 Total spectral efficiency and SNR (dB) with different *L* by giving λ = 2.

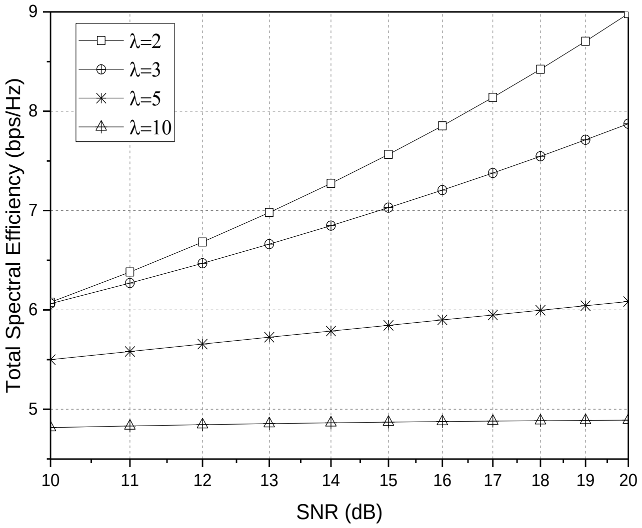

Figure 5.8 Total spectral efficiency and SNR (dB) with varying λ by giving *L* = 3.

5.6.3 Binomial in Nakagami Fading

The total spectral efficiency in Nakagami fading environment is computed from equation (5.43) at diversity of parameters while the number of users is determined as binomial random variable. Then we demonstrate and deliberate the numerical results as shown in Figure 5.9 -5.13.

The total number of UEs is set to be 5 and we assume all users that able to convey their information with 3 subcarriers. Probability of active users is assigned to be 1 in Figure 5.9. This graph show differentiation between total spectral efficiency and SNR while we also vary Nakagami fading index *m* from 1, 2, 4, and 6. Nakagami index denotes a transmission environment which the higher index means the more obvious line-of-sight becomes, having less obstacle between transmitter and receiver. When *m* is larger, the spectral efficiency increases. However *m* equals to 1 and 2, the spectral efficiency slightly rises while increase SNR in the system. The spectral efficiency sharply grow when *m* is 4 and 6. We can summarize that the background noise has more influential when the system has less interference.

In Figure 5.10, we set the total number of UEs to be 5 and each UE use 3 subcarrier to transmit information to eNodeB. The active probability is varied from 0.1, 0.3, 0.5, 0.7, and 0.9 and this graph show relation the spectral efficiency with SNR. It is seen that larger number of active users impacts on the increasing interferences of the whole system and the spectral efficiency reduces; moreover, the background noise scarcely influences on the system.

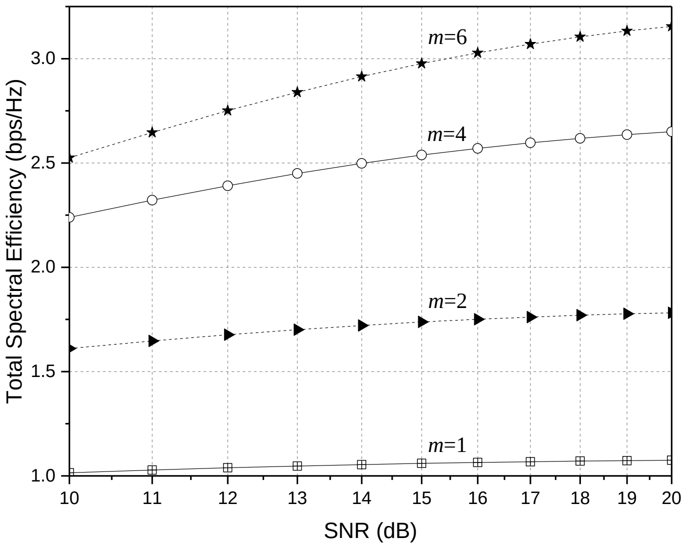

Figure 5.9 Total spectral efficiency versus SNR (dB) with changing *m* by giving $L = 3$, $N = 5$, and $p = 1$.

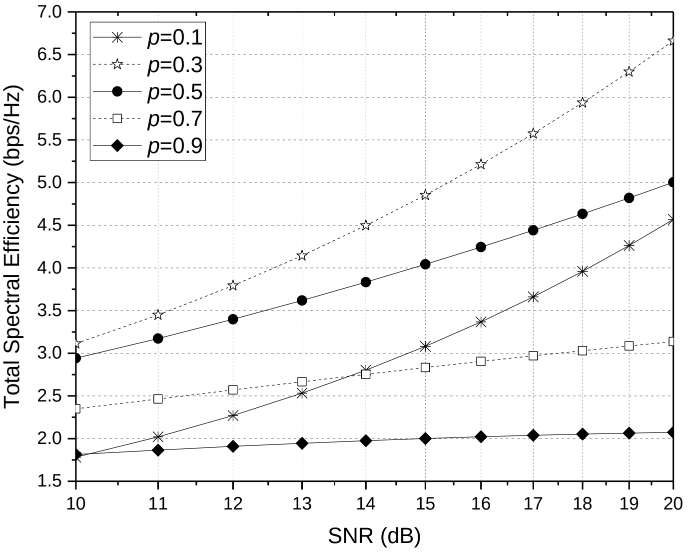

Figure 5.10 Total spectral efficiency versus SNR (dB) with changing *p* by giving $L = 3$, $N = 5$, and $m = 2$.

Total spectral efficiency versus total number of UEs is illustrate in Figure 5.11. We appoint all users that can convey their information with 3 subcarriers (L) and probability of active users (p) is assigned to be 0.7, in addition SNR is 20 dB. Nakagami fading index m is differ from 1, 2, 4, and 6. From this figure, we can conclude that the increasing of total number of users implies the interferences in the system and lessen the overall spectral efficiency. The concluding result from Figure 5.11 is the same as Figure 5.12 which the increasing value of active users represents as adding number of subscribers into the system. Figure 5.12 show the association total spectral efficiency versus probability value of active subscribers. SNR is determined as 20 dB and L equals to 3. Furthermore, the total users is assigned to be 20 and we change m from 1, 2, 4 and 6 to see their relation.

In Figure 5.13, relation between total spectral efficiency and Nakagami fading index is demonstrated while the number of subcarrier varies from 2, 3, 4 and 5. We assume that there are 5 subscribers in the system and probability which users are on equals to 0.7. Signal-to-noise ratio (SNR) defines as 10 dB. From the consequence in the chart, the total spectral efficiency increases when we add the larger subcarrier that users can use into the system. After that, we change m to be larger, being the better environment of transmission path, and the spectral efficiency is exponential increase. We sum up that the fading environment has more effect on the system that allows each subscriber employs more subcarrier. We can see the graph of $L=5$ is highly exponential rising compare with $L=2$.

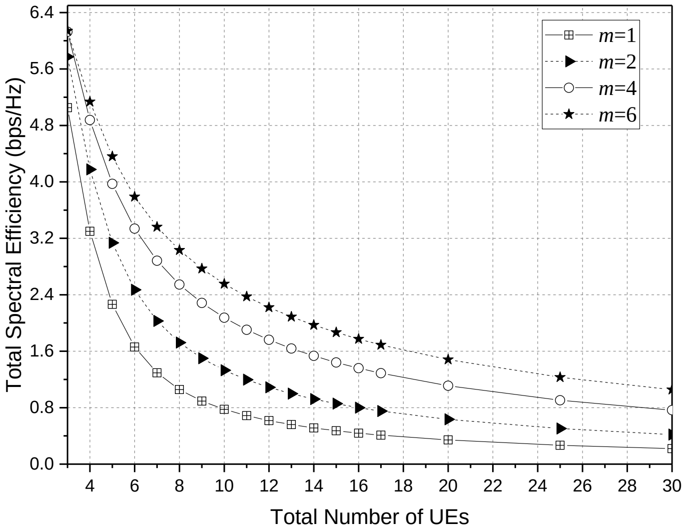

Figure 5.11 Total spectral efficiency versus total number of UEs with changing *m* by giving *L* = 3, *p* = 0.7, and *SNR* = 20 dB.

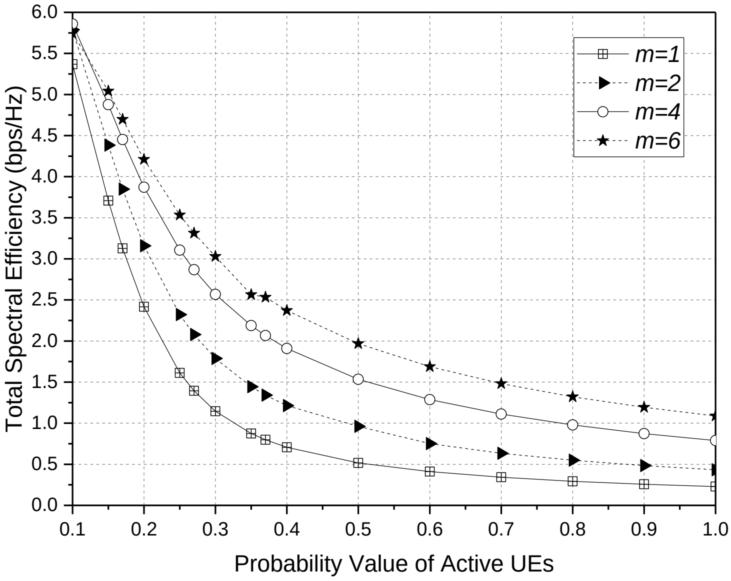

Figure 5.12 Total spectral efficiency versus probability value of active UEs with changing *m* by giving *L* = 3, *N* = 20, and *SNR* = 20 dB.

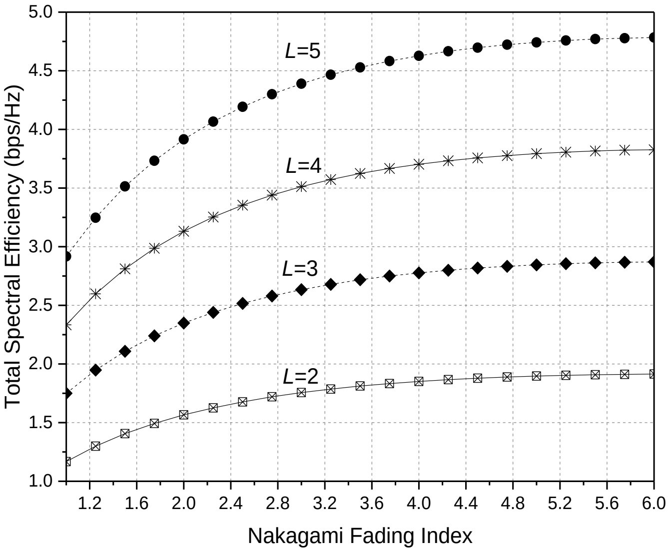

Figure 5.13 Total spectral efficiency versus Nakagami fading index with changing *L* by giving *p* = 0.7, *N* = 5, and *SNR* = 10 dB.

5.6.4 Poisson in Nakagami Fading

From equation (5.45), we gain the total spectral efficiency in Nakagami fading which the number of users is considered as Poisson random variable, and then the spectral efficiency is evaluated to see the variation between the total spectral efficiency and diverse parameters. We analyze the numerical results as illustrated in Figure 5.14-5.17.

In Figure 5.14-5.17, we determine that all UEs use 3 subcarriers to convey their information. Nakagami equals to 3 in Figure 5.14 and signal-to-noise ratio is assigned to 10 dB in Figure 5.15. Average number of active subscribers (λ) in Figure 5.16 and 5.17 is set to 5 and 10 respectively and then we discuss as following.

Firstly, in Figure 5.14, the total spectral efficiency versus SNR while average number of active UES is considered. It displays that the spectral efficiency decreases when we increase number of active user from 2, 3, 5 and 10. Additionally, increasing number of active UEs also show interferences to one another and has more severe influent that background noise, see the different patterns of the lines.

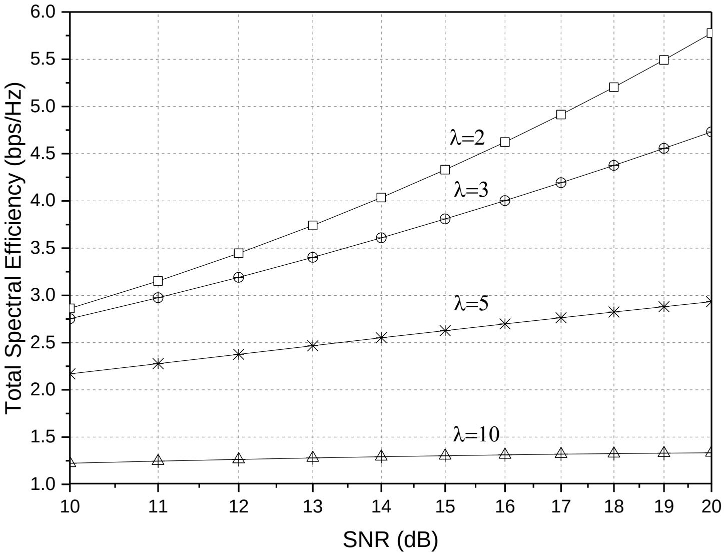

Figure 5.14 Total spectral efficiency with SNR (dB) while vary on λ by giving L = 3 and m = 3.

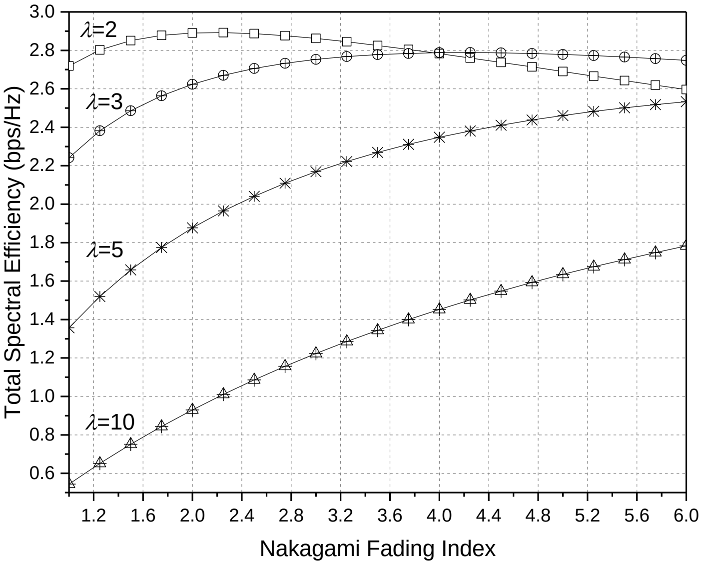

Figure 5.15 Total spectral efficiency with Nakagami fading index while vary on λ by giving L = 3 and SNR = 10 dB.

Then, in Figure 5.15, we can see the variation between the total spectral efficiency and Nakagami fading index while number of active users is varied from 2, 3, 5 and 10. When we change m to be higher, the spectral efficiency rise all various number of active UEs. Furthermore, the environment impacts on the system which has a lot of interferences, see the increasing graph of $\lambda = 5 \text{ and } 10$ compare with $\lambda = 2 \text{ and } 3$, larger number of active UEs means the system has more interferences.

Both Figure 5.16 and 5.17 illustrate the relation between the total spectral efficiency and SNR level while average number of active subscribers is different. The graphs of Figure 5.16 sharply increase when Nakagami fading index *m* is larger, on the other hand, the graphs in Figure 5.17 is scarcely straight line when we rise Nakagami index. Consequently, increasing λ means that there are more interferences in the whole system, the background is not the major trouble for the system if we compare with interferences.

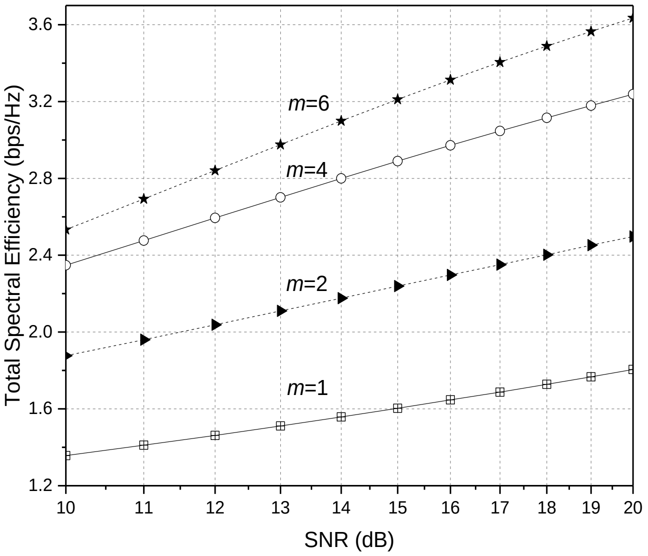

Figure 5.16 Total spectral efficiency with SNR (dB) while vary on *m* by giving $L = 3$ and $\lambda = 5$.

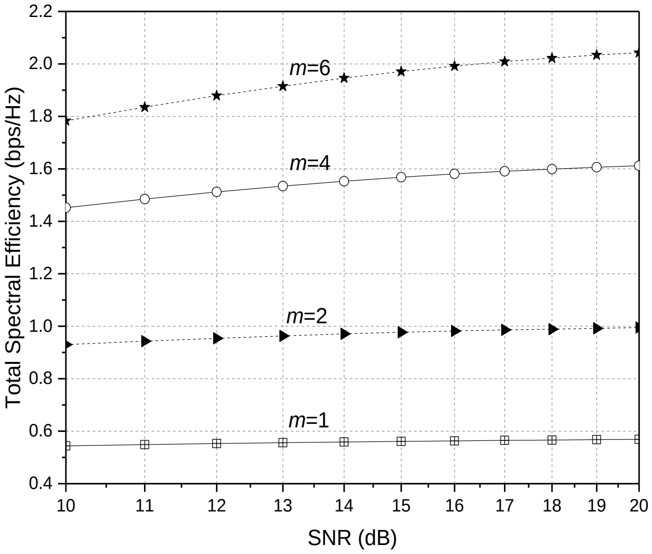

Figure 5.17 Total spectral efficiency with SNR (dB) while vary on m by giving L = 3 and λ = 10.

From the results of Binomial and Poisson in Rayleigh and Nakagami fading channel, sequentially, the total spectral efficiency of Binomial and Poisson cases is similar when the expected values of the active users' number are equal. Seeing Figure 5.4 and 5.8 in term of Binomial and Poisson in Rayleigh fading model, respectively, the total spectral efficiency of both cases equals to 7 bps/Hz when the average number of active UEs in both cases is the same as 3 users. Additionally, the results in Nakagami model are the same as Rayleigh case which the capacities from Figure 5.12 and 5.14 are approximately 1.3 bps/Hz when the expected value of actively users is 10 users. As the results, Poisson random variable seems to be more suitable to represent nature of on-off users because, in this case, we does not need to know the exact number of active and inactive users like Binomial random variable.

5.7 Conclusion

In this chapter, a closed form of uplink spectral efficiency in Rayleigh and Nakagami fading are proposed. Furthermore, the scope of this work is extend to the practical case in which the number of active UEs is random. The distribution of the random process is assumed into two cases, binomial and Poisson random variables, which are suit to the on-off nature of mobile users. From the results, we can calculate the spectral efficiency at different system parameters, for example SNR, active probability, number of employed subcarriers, and number of active UEs which all parameters have an effect on the entire the system to transmit their signals, in addition, the results follow the theory of cellular communications.

CHAPTER VI
CONCLUSION

6.1 Summary

In this chapter, we summarize the main idea of each work, namely, optimal rate scheduling for uplink CDMA, new rate optimization for femto cells, and uplink spectral efficiency for NOMA, from chapter 3 to chapter 5 and our each work involve in existing, modern and future network in order. Moreover, our numerical results can be analyzed and adjusted to be appropriate value for planning or guiding in the systems and make us comprehend more about wireless communication. Finally, in section 6.2, we discuss future work which is presented the form of downlink spectral efficiency for NOMA in Nakagami fading.

6.1.1 Optimal Rate Scheduling for Uplink CDMA

The cross layer protocol on uplink CDMA system for integrated voice and data traffics is proposed in chapter 3. Our concept is power minimization along with the proposed rate adaptation and scheduling technique to serve voice and data traffics effectively. Normally, priority of voice traffic is more than data because the voice traffic need real time transmission. As a result, our protocol, in aspect of scheduling technique, allocates resources to serve voice traffic firstly and then the leftover ones are used by data. Moreover, we regard diversity of data traffic based on their message lengths as well, rate adaptation, this lead to the idea which is the fare share concept. This concept can minimize the maximum transmission time. Then, we calculate our protocol and compare its results with conventional CDMA results, see the details in chapter 3. We can summarize that our proposed is better than the conventional one; however, our data assignment is worse than the conventional due to waiting voice assignment. This causes from the difference from our concept and conventional one; all new entries are sorted and assigned the resource in the order to arrival time in traditional term, and, in our protocol, voice and data are kept in separate queues which each queue is arranged in sequence of arrival time. Consequently, this scheme is not only to appropriate to various loads and traffic statuses but also to minimize the maximum transmission delay.

6.1.2 New Rate Optimization for Femto Cells

This chapter concentrates on theoretical analysis of using small cells, femto cell network, in the existing cell, macro cell, to increase and enhance capacity for the systems. Basically, the femto cells have to share the same spectrum with their macro cell due to limited resources. So the quality of their services to subscribers is worse than usual since increase some femto cell into macro cell like as adding neighboring interferences. Therefore, we propose the data rate optimization of each femto cell which is assured the signal quality under SINR constraint, and our scheme is uncomplicated and capable method by linear programming. Then we calculate a variety of parameters; bandwidth, number of neighboring cells, interfering power and background noise, and discuss them, see the results in chapter 4, by computer simulation. Moreover, some results such as the graph between number of neighboring cells and data rates can guide to plan femto cells into macro cell, and we can adjust value of several parameters from optimization’s equation to be look up tables.

6.1.3 Uplink Spectral Efficiency for NOMA

From chapter 5, the closed form of uplink spectral efficiency in Rayleigh and Nakagami fading models is proposed. Nakagami channel model is general case which displays both non-line-of-sight (Rayleigh) and line-of-sight (Ricean) cases while there is Nakagami fading index to express statements of environment. Note that Rayleigh environment is the same when Nakagami index equals 1. Additionally, we concern the number of active users as binomial and Poisson random variable which present actual states of mobile users, the power gain is consider as exponential random variable different from some work. Finally, the several numerical results from all of conditions, see more details in chapter 5, are illustrated in various parameters such as SNR, probability of active users, number of subcarriers, and the total number of users. All of parameters have an effect on the total uplink spectral efficiency so we can use those results to plan or adjust value in order to support the systems.

6.2 Future Work

As mentioned in chapter 5, the expression of total uplink spectral efficiency in Nakagami fading environment is proposed, additionally, the number of active UEs is set to be the binomial and Poisson random variables to present practical case in cellular communication. Therefore, in future work, we still find the spectral efficiency in the same way as chapter 5 but in term of downlink transmission for NOMA instead.

Figure 6.1 shows the scenario of downlink transmission for NOMA. The eNodeB serves miscellaneous user equipments (UEs), namely UE1, UE2, UE3,…, UE *N* [48], while each UE is multiplexed in power domain based on the radio access technology NOMA. In addition, each UE receiver applies SIC technique to decode its wanted signal [43]. For example, each UE uses SIC receiver to subtract the other signals which it does not want from the total received signals. With rank adaptation, the nearest UE has the highest SINR level whereas further UEs have lower SINR levels due to their distances form the eNodeB.

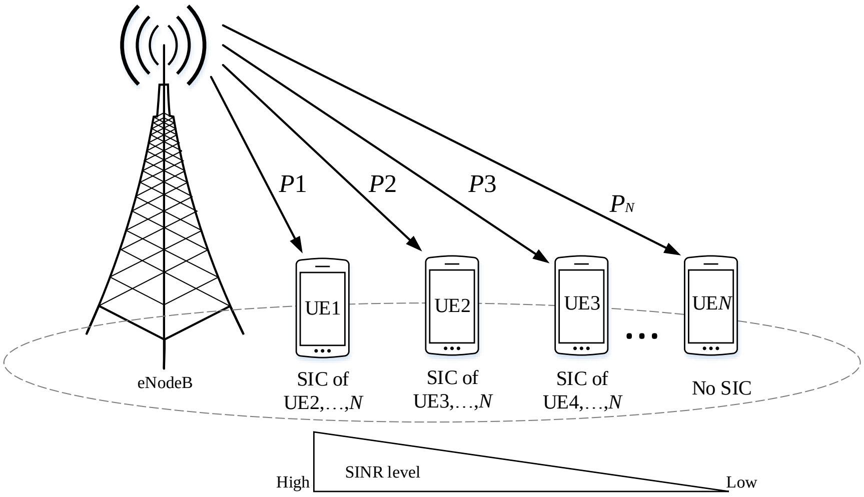

Figure 6.1 Downlink NOMA

We assumes the channel model to be Nakagami term which displays both line-of-sight and non-line-of-sight fading environments, presenting urban and suburban areas respectively. Consequently, UE *n*, $n \in \{1, 2, 3, ..., N\}$, receives the signal power which is formulated as

$$S_n = |h_n|^2 P + \eta_{0,n} \tag{6.1}$$

where $P = \sum_{i=1}^{N} P_i$ is the total signal power transmitted from the eNodeB (see Figure 6.1) and is denoted that $P_1 < P_2 < P_3 < ... < P_N$ is the allocation of power in NOMA technology. $\eta_{0,n}$ is the background noise. Additionally, due to rank adaptation, we have

$$\frac{|h_1|^2}{\eta_{0,1}} > \frac{|h_2|^2}{\eta_{0,2}} > \frac{|h_3|^2}{\eta_{0,3}} > ... > \frac{|h_N|^2}{\eta_{0,N}} \tag{6.2}$$

According to SIC technique, UE *n* can remove the interference from UE *n* + 1. Therefore the spectral efficiency of UE *n* can be formulated as [44]-[46]

$$\begin{aligned} C_1 &= \log_2\left(1 + \frac{P_1|h_1|^2}{\eta_{0,1}}\right), \\ C_2 &= \log_2\left(1 + \frac{P_2|h_2|^2}{P_1|h_2|^2 + \eta_{0,1}}\right), ..., \\ C_N &= \log_2\left(1 + \frac{P_N|h_N|^2}{\sum_{i=1}^{N-1} P_i|h_N|^2 + \eta_{0,N}}\right). \end{aligned} \tag{6.3}$$

As a result, the spectral efficiency of UE *n*, which we focus on, can be defined as

$$C_n = \log_2\left(1 + \frac{P_n|h_n|^2}{\sum_{i=1}^{n-1} P_i|h_n|^2 + \eta_{0,n}}\right) \quad \text{bps/Hz.} \tag{6.4}$$

Thus, we can find the average spectral efficiency as

$$\begin{aligned} C_n &= \mathrm{E}[\log_2(1 + SINR)] \\ &= \int_0^\infty \log_2(1+z) f_{SINR}(z) dz \end{aligned} \tag{6.5}$$

where SINR is determined as $P_n|h_n|^2 / \sum_{i=1}^{n-1} P_i|h_n|^2 + \eta_{0,n}$. With Nakagami channel model, the power gain $|h_n|^2$ become a unit-mean gamma random variable with the probability density function

$$f_{|h_n|^2}(z) = \frac{z^{m-1}}{(m-1)!} m^m e^{-mz} \tag{6.6}$$

where m is Nakagami fading index. When $m=1$, channel model is non-line-of-sight fading environment. Then (6.5) is changed based on logarithm to be

$$C_n = \log_2 e \int_0^\infty \ln(1+z)\, f_{SINR}(z) dz. \tag{6.7}$$

Apparently, the probability density function of SINR is complicated therefore we offer an efficient approach to calculate the average spectral efficiency. This method is described as following.

Assume u to be a unit-mean gamma random variable so a probability density function is

$$f(u) = \frac{u^{m-1}}{(m-1)!} m^m e^{-mu} \tag{6.8}$$

where $z = u/v$ in which $u = \left|h_{i,l}\right|^2$ and $v = 1/P_{n,l}\left(\sum_{i=1,i\neq n}^{N} P_{i,l}\left|h_{i,l}\right|^2 + N_0\right)$, then

$$\mathrm{E}\left[\ln(1+z)\middle|v\right] = \int_0^\infty \frac{1}{z}\left[1 - \frac{1}{(1+z)^m}\right] \mathrm{MGF}(mz) dz \tag{6.9}$$

where $\mathrm{MGF}(mz) = \mathrm{E}[\mathrm{e}^{-zmv}]$ is the moment generating function of v, see the proof from (5.34) to (5.36).

From (5.9), in chapter 5, the MGF can be solved in a simple form as

$$\mathrm{MGF}(mz) = \mathrm{E}\left[e^{-\frac{zm}{p_n}\left(\sum_{i=1,i\neq n}^{n-1} P_i |h_n|^2 + \eta_{0,n}\right)}\right] = e^{-\frac{zm\eta_{0,n}}{P_n}} \prod_{i=1}^{n-1}\left(\frac{1}{1+\frac{P_i}{P_n}z}\right). \tag{6.10}$$

We replace (6.10) into (6.5), as a result, we gain the downlink average spectral efficiency in Nakagami fading.

Afterward, we have to calculate the downlink spectral efficiency by computer simulation through several system parameters; signal-to-noise ratio (SNR), Nakagami fading index, and power allocation. We will adjust and analyze the numerical results which each of parameter has an impact on the value of spectral efficiency.

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