PERFORMANCE ANALYSIS OF FREQUENCY REUSE SCHEMES IN CELLULAR MOBILE ENVIRONMENT

SUBMITTED BY

JASIM UDDIN AHMED
ID: 063-19-467

MD. ABDUL HANNAN
ID: 063-19-504

NUSRAT JAHAN

ID: 063-19-515

A project report presented in partial fulfillment of the requirements for the degree of Bachelor of Science in Electronics and Telecommunication Engineering

SUPERVISED BY

A.K.M Fazlul Haque
Assistant Professor
Department of Electronics and Telecommunication Engineering
Daffodil International University

DAFFODIL INTERNATIONAL UNIVERSITY
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APPROVAL

This project titled '**Performance Analysis of Frequency Reuse Schemes in Cellular Mobile Environment**' submitted by Md. Abdul Hannan, Jasim Uddin Ahmed, and Nusrat Jahan to the Department of Electronics and Telecommunication Engineering, Daffodil International University, has been accepted as satisfactory for the partial fulfillment of the requirement for the degree of Bachelor of Science in Electronics and Telecommunication Engineering and approved as to its style and contents. The presentation was held on September 17, 2010.

Board of Examiners

Dr. Md. Golam Mowla Choudhury
Professor and Head
Department of Electronics & Telecommunication Engineering
Daffodil International University

(Chairman)

Dr. Subrata Kumer Aditya
Professor and Chairman
Department of Applied Physics
Dhaka University

(External Member)

A. K. M. Fazlul Haque
Assistant Professor
Department of Electronics & Telecommunication Engineering
Daffodil International University

(Internal Member)

Md. Mirza Golam Rashed
Assistant Professor
Department of Electronics & Telecommunication Engineering
Daffodil International University.

(Internal Member)

DECLARATION

We hereby declare that the work presented in this thesis report titled “Performance Analysis of Frequency Reuse Schemes in Cellular Mobile Environment” is done by us under the supervision of Mr. A.K.M Fazlul Haque, Assistant Professor of Electronics and Telecommunication Engineering, Daffodil International University, in partial fulfillment of the requirements for the degree of Bachelor of Science in Electronics and Telecommunication Engineering. We also declare that this thesis is our original work. As far as our knowledge goes, neither this report nor any part there of has been submitted else where for the award of any degree or diploma.

Supervised by:

A.K.M Fazlul Haque
Assistant Professor
Department of Electronics & Telecommunication Engineering
Daffodil International University

(Signature)

Submitted by:

Jasim Uddin Ahmed
ID: 063-19-467
Department of Electronics & Telecommunication Engineering
Daffodil International University

(Signature)

Md. Abdul Hannan
ID: 063-19-504
Department of Electronics & Telecommunication Engineering
Daffodil International University

(Signature)

Nusrat Jahan
ID: 063-19-504
Department of Electronics & Telecommunication Engineering
Daffodil International University

(Signature)

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ABSTRACT

This thesis is on "**Performance Analysis of Frequency Reuse Schemes in Cellular Mobile Environment".** Frequency planning is the prime important issues for the RF engineers. The principle goal of the analysis done in various frequency reuse scheme is for proper frequency planning.

In this thesis, the performances for frequency reuse schemes have been analyzed. Using MATLAB R2008a, the performance of frequency reuse factors for both OMNI and Sectoring cell has been evaluated. In order to fulfill the traffic demand and all the factors related with the performance of respective model for different environment have also been proposed. With considering the traffic variation in different geographical areas i.e. rural, urban, highways etc., the respective model not only provide the satisfactory level of traffic but also provide the standard interference level.

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Introduction to Cellular Communication System

1.1 History of Cellular Communication System

In a separate segment of communications, another revolution was taking place—cellular telephones. In the late 1970s AT&T Bell Laboratories began working with several leading United States and Japanese companies to create a cellular telephone system based on dividing coverage areas into small cells and reusing frequencies. Previous mobile telephone technologies operated on limited numbers of channels, thus limiting the number of users in any given coverage area to a very small number. The result was low user use and costly service and equipment. A core group was created to develop a standard called the Advanced Mobile Phone Service (AMPS). In December 1983, AMPS was launched in Chicago, Illinois with great fanfare. It proved immensely popular. Now before someone says, "Hey, wait a minute, AMPS wasn't the first cellular system!," let's give that credit to the Nordic Mobile Telephone (NMT) system. NMT was launched in 1981 in Scandinavia, but in terms of market size, AMPS potential market in the United States was vastly larger. AMPS quickly spread to other countries in North and South America, Korea, and Australia. A similar standard, Total Access Communications System (TACS), was developed in the United Kingdom as well.

Today, there are many competing standards in mobile telephones worldwide. In fact the word "mobile" means something entirely different today than it did in 1983. The majority of cellular telephones sold today are hand-held, not permanently installed in vehicles. Each competing standard is incompatible with others on the basic technology used, but to the end user, all cellular telephones should perform the basic functions expected. (Even though many new carriers would like to distinguish themselves from "cellular" companies by calling themselves "PCS" companies, we consider both as cellular applications. This is not to say that companies with PCS spectrum in the 1900 MHz band may or may not have some advantages over carriers with traditional spectrum allocations in the 800 MHz band. But because many carriers own spectrum in both bands this is a moot point.)

Cellular radio got its name from the physical layout of a system in a pattern resembling a honeycomb figuratively. Each cell site operates on a different frequency so that neighboring cells do not interfere with one another. However, frequencies can be re-used if they are separate by sufficient distance. This is referred to as the re-use pattern.

1.2 Evolution of cellular communication

1.2.1 O Generation (0G)

Before 1970s mobile technology was non cellular. The OG standards are MTS (Mobile Telephone System) and IMTS (Improved Mobile Telephone System).

Year	Invention
1873	Telegraph
1873	Maxwell's electromagnetic theory
1877	Telephone
1895	First wireless transmission
1909	First radio broadcast
1940	Push-to-talk(Half duplex)
1946	First commercial mobile i.e; MTS (Mobile Telephone System)
1960	First full-duplex mobile i.e; IMTS (Improved Mobile Telephone System)

1.2.2 First Generation (1G)

In late 1970s 1G cellular system introduced a quantum leap. 1G use FDMA FM technology and the standards are:

Year	Standard	Frequency band	Country
1979	NTT-MTS (Nippon Telegraph and Telephone Corporation)	800MHz	Japan-MTT
1983	AMPS(Advanced Mobile Phone System)	800Mhz	Us-Bell lab
1981-86	NMT (Nordic Mobile Telephone)	450/900MHz	Scandinavian
1985	TACS (Total Access Communication System)	900MHz	England
1985	C-450	450MHz	Germany
1985	Radiocom	450MHz	France
1985	RMTS (Remote Modem Transfer Switch)	450MHz	Italy

1.2.3 Second Generation (2G)

2G use TDMA and CDMA techniques. The 2G standards are:

Year	Standard	Frequency band	Channel bandwidth	Country
1992	GSM (Global System for Mobile Communication)	900MHz	200kHz	Asia, Australia, Europ, South America
1991	D-AMPS (Digital Advanced Mobile Phone System) IS-136 (Intellec Standard-136) NADC (North American Digital Cellular)	800mHz	300kHz	South America, North America, Australia
1993	PDC (Pacific Digital Cellular)	800mHz	25kHz	Japan
1995	IS-95	800mHz	1.25kHz	North America, South America, Australia,Japan, koria,China

1.2.4 Third Generation (3G)

The ITU IMT 2000 standards are separated into two organizations reflecting the 3G camps:

- 3GPP (3rd Generation Partnership Project) for wider band CDMA standard
- 3GPP2 for CDMA 2000 standard. (US along)

Standard	Channel Bandwidth	Country
UMTS(Universal Mobile Telecommunication System) - WCDMA	5MHZ	Worldwide
UWC-136 (Universal Wireless Communication) - WCDMA	5MHZ	Japan
FOMA (Freedom of Mobile Multimedia Access) - WCDMA	5MHZ	USA, Canada
CDMA 2000 - CDMA	1.25MHz	North Amesica

1.3 Cellular Communication System

A cellular mobile communications system uses a large number of low-power wireless transmitters to create cells—the basic geographic service area of a wireless communications system. Variable power levels allow cells to be sized according to the subscriber density and demand within a particular region. As mobile users travel from cell to cell, their conversations are "handed off" between cells in order to maintain seamless service. Channels (frequencies) used in one cell can be reused in another cell some distance away. Cells can be added to accommodate growth, creating new cells in unserved areas or overlaying cells in existing area [13].

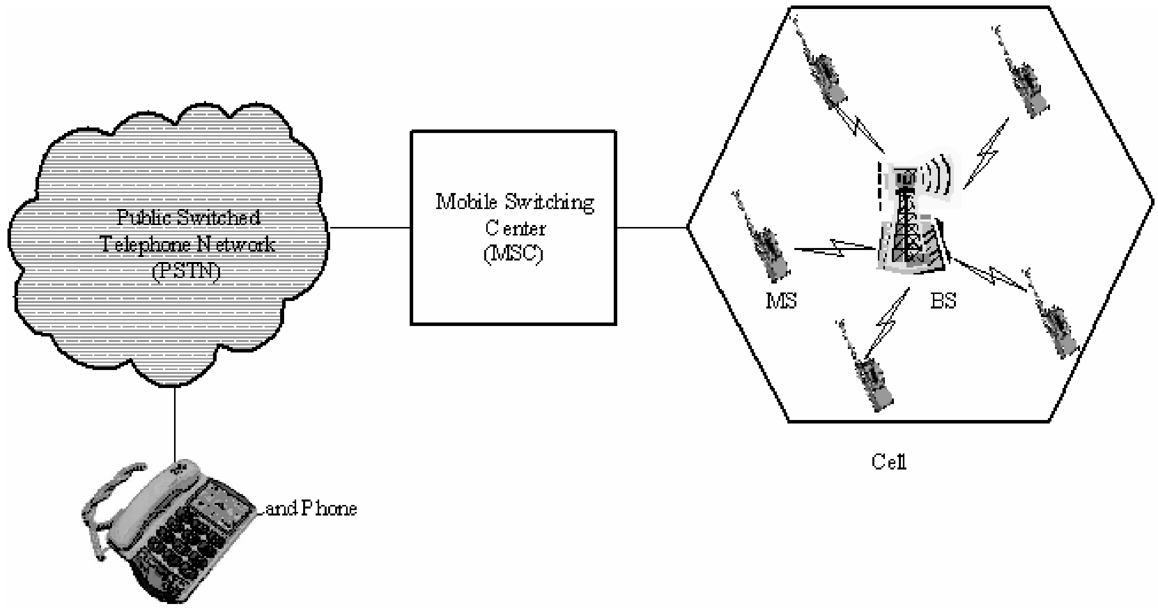


Figure 1.1: Basic cellular communication system

The cellular concept was a major breakthrough in solving the problem of spectral congestion and user capacity. It offered very high capacity in a limited spectrum allocation without any major technological changes. The cellular concept is a system-level idea which calls for replacing a single, high power transmitter (large cell) with many low power transmitters (small cells), each providing coverage to only a small portion of the service area. Each base station is allocated a portion of the total number of channels available to the entire system, and nearby base stations are assigned different groups of channels so that all the available channels are assigned to a relatively small number of neighboring base stations. Neighboring base stations are assigned different groups of channels so that the interference between base stations (and the mobile users under their control) is minimized. By systematically spacing base stations and their channel groups throughout a market, the available channels are distributed throughout the geographic region and may be reused as many times as necessary so long as the interference between cochannel stations is kept below acceptable levels. As the demand for service increases (i.e., as more channels are needed within a particular market), the number of base stations may be increased (along with a corresponding decrease in transmitter power to avoid added interference), thereby providing additional radio capacity with no additional increase in radio spectrum. This fundamental principle is the foundation for all modern wireless communication systems, since it enables a fixed number of channels to serve an arbitrarily large number of subscribers by reusing the channels throughout the coverage region.

Furthermore, the cellular concept allows every piece of subscriber equipment within a country or continent to be manufactured with the same set of channels so that any mobile may be used anywhere within the region.

1.4 Cellular Frequency Bands

All cellular phone networks worldwide use a portion of the radio frequency spectrum designated as Ultra High Frequency, or "UHF", for the transmission and reception of their signals. The UHF band is also shared with Television, Wi-Fi and Bluetooth transmission. The cellular frequencies are the sets of frequency ranges within the UHF band that have been allocated for cellular phone use [14].

Due to historical reasons, radio frequencies used for cellular networks differ in the Americas, Europe, and Asia. The first commercial standard for mobile connection in the United States was AMPS, which was in the 800 MHz frequency band. In Nordic countries of Europe, the first widespread automatic mobile network was based on the NMT-450 standard, which was in the 450 MHz band. As mobile phones became more popular and affordable, mobile providers encountered a problem because they couldn't provide service to the increasing number of customers. They had to develop their existing networks and eventually introduce new standards, often based on other frequencies. Some European countries (and Japan) adopted TACS operating in 900 MHz. The GSM standard, which appeared in Europe to replace NMT-450 and other standards, initially used the 900 MHz band too. As demand grew, carriers acquired licenses in the 1800 MHz band. (Generally speaking, lower frequencies allow carriers to provide coverage over a larger area, while higher frequencies allow carriers to provide service to more customers in a smaller area.)

In the U.S., the analog AMPS standard that used the Cellular band (800 MHz) was replaced by a number of digital systems. Initially, systems based upon the AMPS mobile phone model were popular, including IS-95 (often known as "CDMA", the air interface technology it uses) and IS-136 (often known as D-AMPS, Digital AMPS, or "TDMA", the air interface technology it uses.) Eventually, IS-136 on these frequencies was replaced by most operators with GSM. GSM had already been running for some time on US PCS (1900 MHz) frequencies.

And, some NMT-450 analog networks have been replaced with digital networks using the same frequency. In Russia and some other countries, local carriers received licenses for 450 MHz frequency to provide CDMA mobile coverage.

Many GSM phones support three bands (900/1800/1900 MHz or 850/1800/1900 MHz) or four bands (850/900/1800/1900 MHz), and are usually referred to as tri band and quad band phones, or world phones; with such a phone one can travel internationally and use the same handset. This portability is not as extensive with IS-95 phones, however, as IS-95 networks do not exist in most of Europe.

Mobile networks based on different standards may use the same frequency range; for example, AMPS, D-AMPS, N-AMPS and IS-95 all use the 800 MHz frequency band. Moreover, one can find both AMPS and IS-95 networks in use on the same frequency in the same area that do not interfere with each other. This is achieved by the use of different channels to carry data. The actual frequency used by a particular phone can vary from place to place, depending on the settings of the carrier's base station.

1.5 Features of Cellular Communication System

1.5.1 Mobility

Mobility is one of the major features of cellular communication systems. It implies that a cellular call, any time within the service area, would be able to maintain the same cell without service interruption, while in motion. This is attributed to the built-in hand-off mechanism, which is a process of changing the carrier frequency. Its primary purpose is to assign a new frequency while a mobile moves into a new cell. This is accomplished by setting a handoff threshold; that is, if the received signal level is too low and reaches a predefined threshold, any system controller- namely the mobile switching center (MTX) – provides a stronger free channel (frequency) from an adjacent cell. This process continues from cell to cell as long as the mobile is in the coverage area, maintains the call, and is also in motion [1].

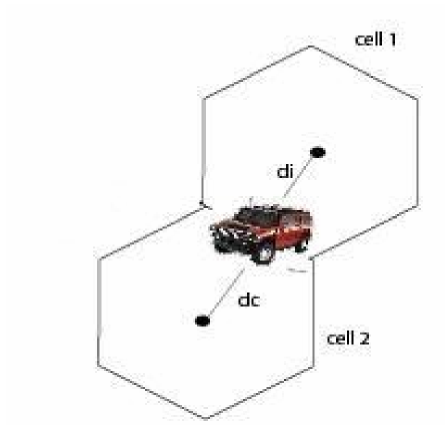


Figure 1.2: Illustration of mobility

1.5.2 Capacity

Channel capacity is measured by the available voice channels per cell, translated into Erlangs. Because there are 21 control channels, the number of voice channels is 333-21=312 in the NES and 416-21=395 in the ES. The channel capacity per cell or per cluster in a seven cell plane can be calculated as:

NES channel capacity = 312/7 = 44 voice channel per cell
= 35 Erlangs/cell @ 2%GOS
= 35*7 = 245 Erlangs/cluster @2% GOS
= 7350 subscribers (@ 30Subs/Erlangs typical)

Similarly with ES, the channel capacity becomes

ES channel capacity = 312/7 = 395/7= 56 channels per cell
= 46 Erlangs/cell @ 2%GOS

= 46*7 = 312 Erlangs/cluster @2% GOS

= 9660 subscribers (@ 30Subs/Erlangs typical)

Assuming 10 square miles/cell in a rural area, a cluster of seven cells translates into 7350 subscriber/7000 square miles in the NES and 9660 subscribers/7000 square miles in the ES.

1.5.3 Frequency reuse

Frequency reuse is the system in which users in different geographic location (different cells) may simultaneously use the same frequency channel. It is expressed by N or K.
The factor N is called the cluster size, where cluster is a group of identical cells in which all of the available channels (frequencies) are evenly distributed. A larger cluster size indicates that the ratio between the cell radius and the distance between co-channel cells is small. Conversely a small cluster size indicates that co-channel cells are located much closer together. The value for N is a function of how much interference mobile or base station can tolerate while maintaining a sufficient quality of communications. From a design view point, the smallest possible value of N is desirable in order to maximize capacity over a given coverage area.

Because there are a limited number of channels, these channel groups are reused are regular distance intervals. This is an important engineering task that requires a good compromise between capacity and performance. The mechanism that governs this process is called frequency planning. Several frequency planning are available and is obtained by the following formula [2]:

$$N=i^2+ij+j^2$$

Where i and j are non-negative integer.

Here, i=1, j=2, N=1+2+4=7

N= Frequency Reuse factor

Some of the most widely used frequency Planning techniques are as follows [1]:

- N= 3 frequency reuse plan
- N = 4 frequency reuse plan
- N = 7 frequency reuse plan
- N = 9 frequency reuse plan

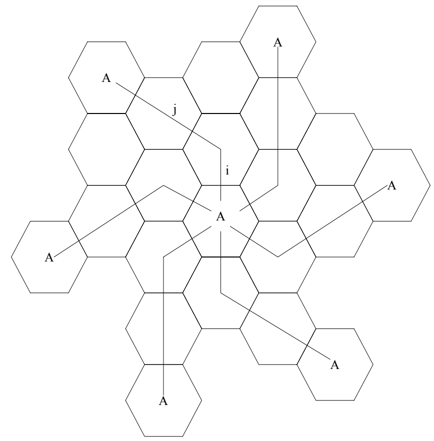


Figure 1.3: Finding frequency reuse factor

The N = 3 and N = 9 frequency plans are relatively unknown. However, since the advent of TDMA techniques, these plans are becoming popular among cellular industries for enhancing channel capacity.

1.5.4 Roaming

A user can have access to communication or access the coverage where it is. This principle is called roaming. Each service provider has its limited coverage. There are many cellular operators within the same city, using different switch, radios, and cell site equipment. But a subscriber is registered to one operator only. As a result, an agreement between these operators is needed to provide service to any subscriber irrespective of a call's origin. This is accomplished by means of a separate link between various switches, which is established by the [s-4] link protocol [1]. A mobile moving out of its own territory and establishing a call from a foreign territory is known as a roamer and the process itself is known as roaming. Roaming enhances mobility.

1.5.5 Data Transmission

Data Transmission over the analog cellular channel is a new feature in today's cellular communication systems. This is attributed to the recent introduction of cellular digital packet data (CDPD). It is based on existing cellular networks and uses an unused AMPS channel from a given frequency in a cell site. Numerous services can be performed and received over the CDPD channel, including fax transmission, compute data transmission, stock exchange portfolio access, news wire service access, commodity prices list access, travel information, and many more services that currently rely on e-mail.

The CDPD channel is composed of a forward CDPD (FOCDPD) channel and a reverse CDPD (RECSPS) channel over which data transmission takes place between the base station and the mobile, Data transmission is based on encoding 47 data bits into a (63,47) Reed-Solomon code, which can correct as high as (63-47)/2 =8 errors. The encoded word (block) is then transmitted by means of GMSK modulation at 19.2Kbps [1].

Note that in GMSK modulation, the power spectral density is such that more than 90% energy is retained within a tr4ansmission bandwidth of 19.2*1.2 = 23 kHz, which is sufficient for the available 30kHz channel spacing. As a result, adjacent channel interference is greatly reduced and is expected to be lower than TDMA. On the receiving side, the RF signal is demodulated, decoded and finally the original data are recovered.

1.6 Analog Cellular Communication System

Analog cellular network is the 1st generation (1G) cellular communication system. The design of the voice communication of this generation was made with analog signals. Two types of analog cellular networks are

- Advanced Mobile phone System (AMPS)
- Total Access Communication system(TACS)

Advanced Mobile phone System (AMPS) is one of the earliest commercial cellular communication systems. AMPS technology is currently deployed throughout North America and AMPS derivative systems are deployed in a many of worldwide cellular markets. Generally AMPS operates in ISM 800 MHz band and uses FM and FSK for modulation. AMPS is an analog cellular system using FDMA [15].

Total Access Communication system (TACS) is the European version of AMPS.A typical TACS system operates in 450 MHz and 900 MHz band.

1.7 Digital Cellular Communication System

In order to provide higher quality and less noise prone mobile voice communications, the second generation of cellular phone network was developed. While the 1^{st} generation was designed for analog voice communication, the second generation was mainly designed for digitized voice [15].

Five major systems for digital cellular systems are:

- Digital Advanced Mobile phone System (D-AMPS)
- Global System for Mobile Communication (GSM)
- Code Division Multiple Access (CDMA)
- General Packet Radio System (GPRS)
- Personal Communication System (PCS)

Chapter 2
Elements of Cellular Communication System

2.1 Introduction

The generic cellular communication system, shown in figure 2.1 is an integrated network comprising a land based wireline telephone network and a composite wired - wireless network. The land based network is a traditional telephone system in which all telephone subscribers are connected to a central switching network, commonly known as Public switched Telephone Network (PSTN). The composite wired-wireless system is the basis of todays cellular system. The Mobile Switching Center (MSC) is the heart of this system.

2.2 Elements of Cellular Communication System

The cellular communications system comprise four major components that process together to supply mobile service to subscribes

1. Public switched telephone network (PSTN)
2. Mobile telephone switching office(MTSO)
3. Cell site with antenna system
4. Mobile subscriber unit (MSU)

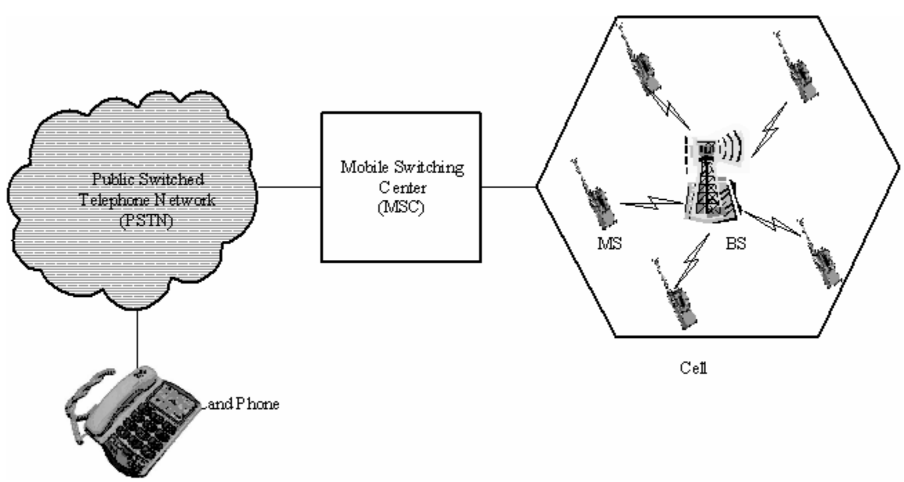


Figure 2.1: Basic elements of cellular communication system

2.2.1 Public switched telephone network (PSTN)

PSTN is set up from local networks, the exchange area networks, and the long-haul network. All of these networks connect cell phone and other communication devices on a global basis. The basic telecommunication network involves terminals, a public switching telephone network, cables, and microwave links or optical fiber links. A terminal can be a simple telephone set, a computer, a modem, or several workstations. The PSTN is a digitally controlled switching matrix that provides connectivity between two or more terminals. Depending on the population density, a PSTN may have well over 100000 terminals connected to it. As a result, a major metropolitan area may have more than one PSTN switch connected to each other [1].

Data transmission take places over cable, microwave links, or optical fiber links, providing global coverage via satellites, underwater cables, and optical cables. Various transmission equipment and protocol converters are also used to established global connectivity.

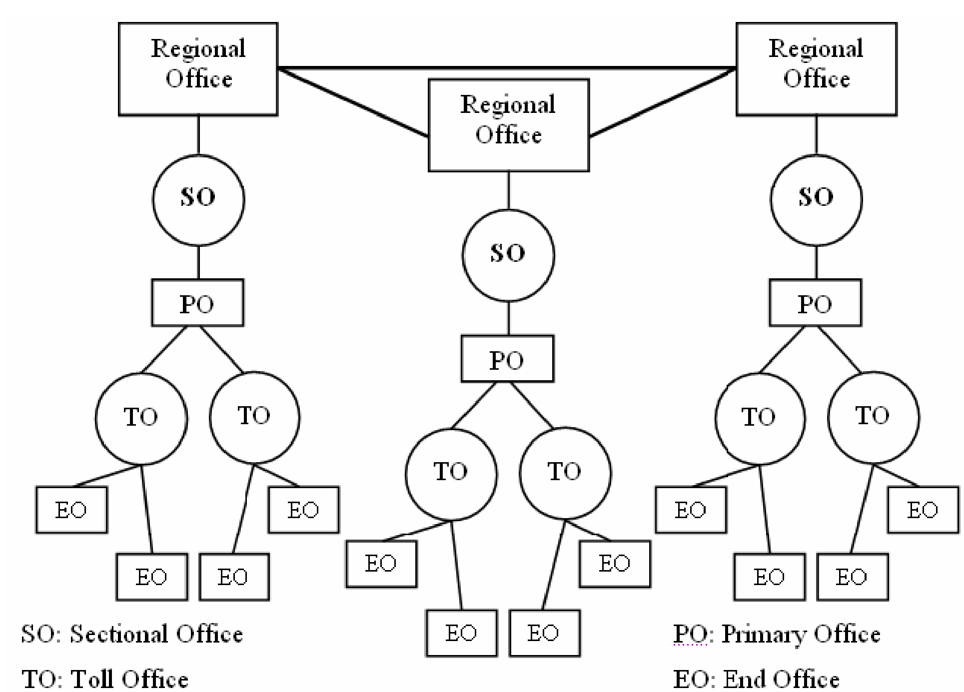


Figure 2.2: Hierarchy of switches in a telephone network

It is also necessary to provide telephone services to small communities such as offices and business communities in a cost effective manner. This is accomplished by means of a small switch known as a private branch exchange (PBX), which enables an internal office call to bypass the PSTN. PBX switches are generally installed within the business subscriber's premises. Several PBXs can be installed in one or in different buildings and are connected to each other by cables.

2.2.2 Mobile telephone switching office (MTSO)

MTSO is the main office for cell phone switching. In analog cellular networks, the mobile switching center (MSC) manages the system operation. The MSC is a digital cellular switching product, supporting 800-MHz cellular communication systems. It has different acronyms such as digital multiplex switch-mobile telephone exchange (DMS-MTS), mobile telephone switching office (MTSO), etc depending on the manufacturer.

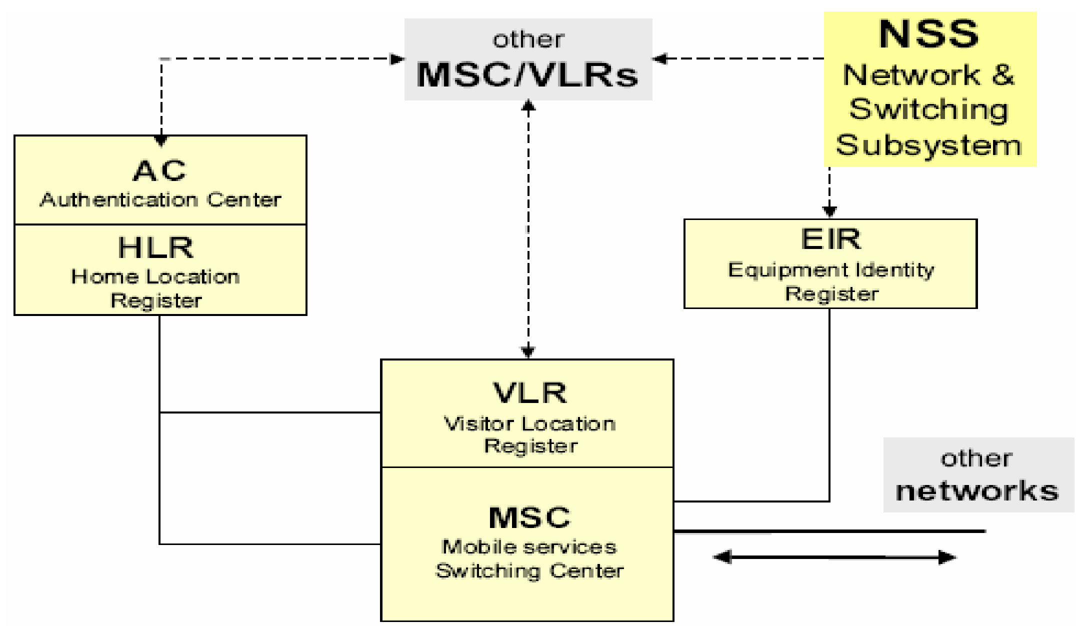


Figure 2.3: Mobile Switching Center with its subsystem

The MSC is a part of the PSTN family, designed to provide the following cellular Function [16]

1. Manage and control cell site equipment and connections.
2. Support multiple-access technologies such as AMPS, CDPD, and CDMA.
3. Provide the PSTN interface.
4. Provide a visitor location register (VLR).
5. Provide a home location register (HLR).
6. Support intersystem connectivity (IS-41).
7. Support call processing functions.
8. Provide billing and operation measurement (O&M).
9. Provide routing functionality.
10. Provide legal interception.
11. Provide call supervision.
12. Provide processing of mobile specific services
13. Provide mobility management
14. Support overloads handling.

2.2.3 Cell site with antenna system

Cell site can be referred to the hardware location of radio equipment. The hardware location consists of power source, interface equipment, radio frequency transmitters and receivers and antenna systems.

2.2.3.1 Base station controller (BSC)

The Base Station Controller BSC is, the controlling element, the heart and center element of the BSS.

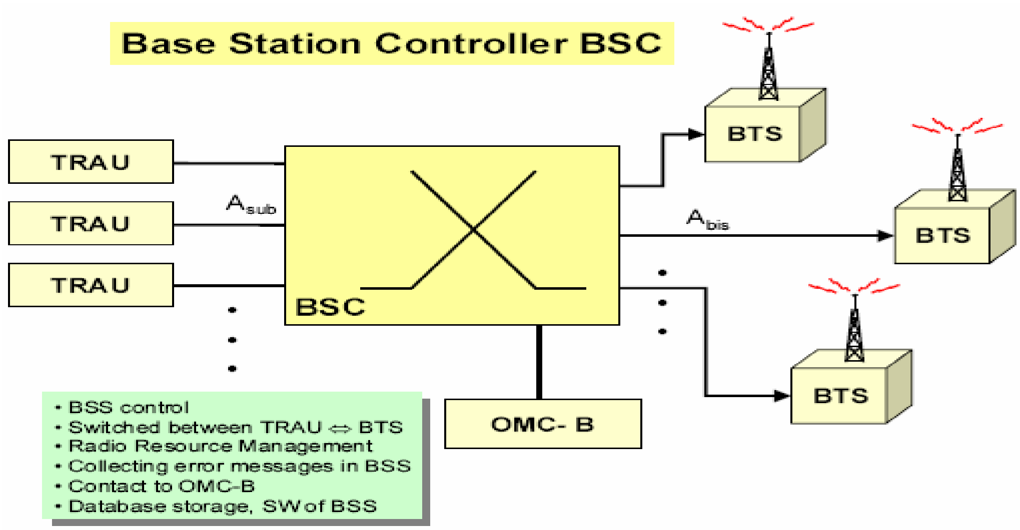


Figure2.4: Base Station Controller with its subsystem

The function of BSC is

1. Switching of the user traffic between individual TRAUs and BTSs.
2. Control and monitoring of the connected TRAUs and BTSs.
3. Radio resource management for all connected BTSs.
4. Storage of the BSS configuration.
5. Back-up storage of the total BSS software for first system restart.
6. Evaluation of signaling information from MSC via TRAU and MS via BTS
7. Sampling of operation and maintanence of BSC, TRAUs and BTSs.

2.2.3.2 Base Transceiver Station (BTS)

A BTS is the module which operates an individual cell and realizes the radio0 interface. An BTS encompasses all applications concerning radio transmission (sending, receiving), as well as the air interface specific signal processing. The BTS is connected via the Abis interface with the BSC and via Um interface to the MSs [16].

The function of BTS is

1. Channel coding: To protect the transmission, incoming information is provided with parity bits and redundancy and spread in time over several HF bursts (interleaving).

2. Ciphering: After channel coding, the transmission information and the subscriber data is coded to prevent illegal interception.

3. Burst block information: The information is organized in blocks of a particular length (burst blocks). A so-called training sequence is added for synchronization and analysis of transmission quality.

4. Modulation: The carrier frequency is created in the 900/1800 MHz range and the information is modulated upon this carrier.

5. Power control: control the power level of the BTS and MS

6. Timing advance: calculation of the distance of the MS from the BTS; the MS are informed of necessary transmission advance.

7. Frequency hoping: a feature which enhances the reliability of information transfer.

8. Synchronization: providing of mobile stations with frequency and time synchronization information.

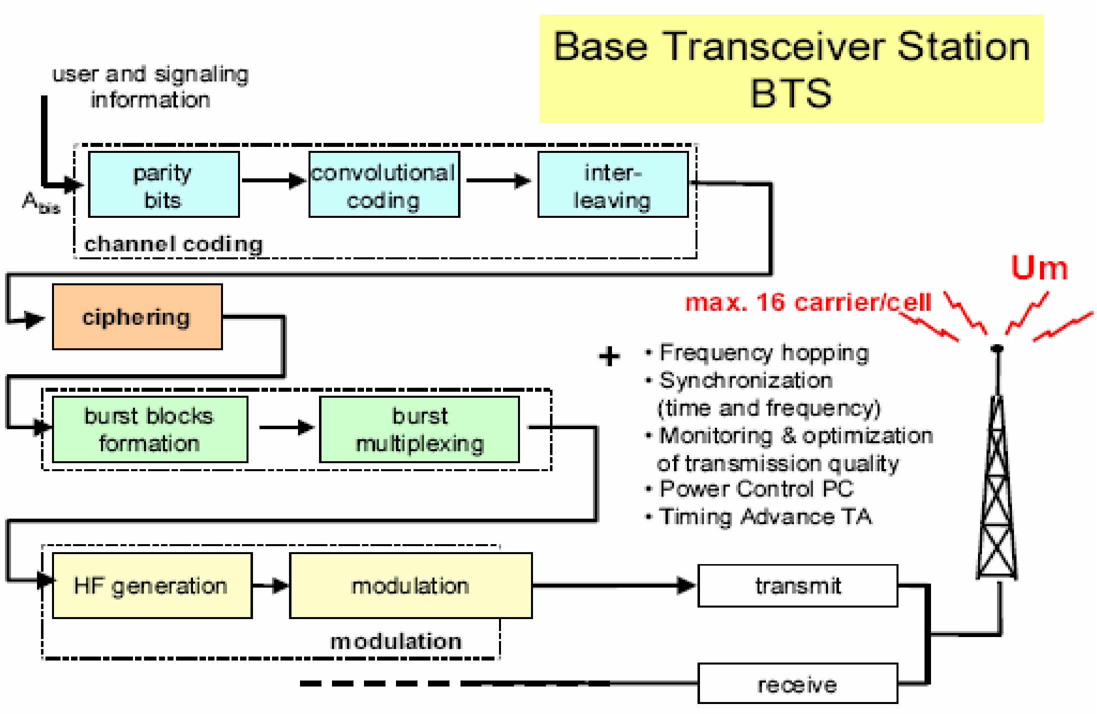


Figure 2.5: Function of Base Transceiver Station

2.2.3.3 Antennas and Antenna Systems

There are three major types of antenna systems in use today:

- Omni directional
- Semi directional
- Highly directional

In addition, there are variations on the implementation and management of these antenna types which results in the sectorized and phased-array antennas. These will also be covered in this section. Finally, we'll look very briefly at the forthcoming MIMO antenna systems that are currently being standardized by the IEEE and implemented in pre standardized ways by many vendors [4].

2.2.3.3.1 Omni directional/Dipole Antennas

Omni directional antennas, the most popular type being the dipole antenna, are antennas with a 360-degree horizontal propagation pattern. In other words, they propagate most of their energy outward in a 360-degree pattern shaped much like a doughnut—though a very thick one. The omni directional antenna provides coverage at an angle upward and directly out horizontally as is shown in the Elevation chart in Figure 2.6.

Inspecting the Elevation chart in Figure 2.6 reveals that an omni directional antenna propagates most of its energy to the right and left of the antenna (from a side view) and very little energy directly above the antenna. At the same time, the Azimuth chart shows a fairly even distribution around the antenna (from a top-down view). This is the common propagation characteristic of omni directional antennas [4]. Figure 2.7 shows a number of actual omni directional antennas.

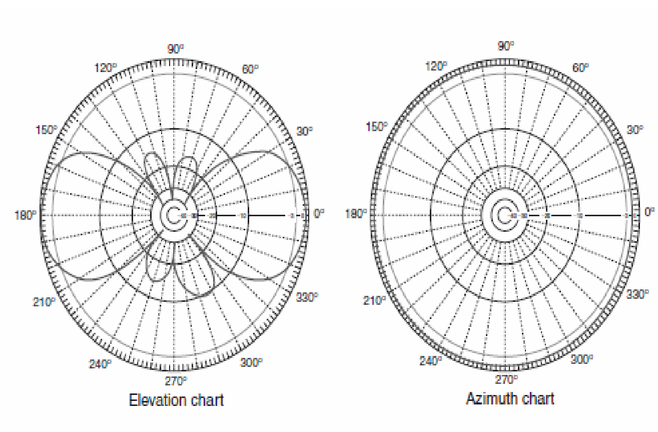


Figure 2.6: Omni directional antenna Elevation chart

Figure 2.7: Omni directional antenna

Omni directional Antenna Usage

The omni directional antenna is most commonly used indoors to provide coverage throughout an entire space; however, they have become more and more popular in outdoor usage for either hotspots or central antennas in PtMP configurations. Omni-directional antennas may be mounted on poles, masts, towers, ceilings, or desktops and floors. They provide coverage on a horizontal plane with some coverage vertically and outward from the antenna. This means they may provide some coverage to floors above and below where they are mounted in some indoor installations. Because all antennas use passive gain—they focus the RF energy—it is important to consider the impact of this passive gain on any antenna that you implement. In the case of omni directional antennas, the result is that devices directly above or below the omni directional antenna may have a very weak signal or even be unable to detect the signal. This is due to the primary signal being focused outwardly on a horizontal plane.

You can use antennas that have higher dBi gain, such as 12 or 15 dBi omni antennas; however, you must keep the impact of these higher-gain antennas in mind. As an example, consider the two Elevation charts side by- side in Figure 2.8 The one on the left is from a 4 dBi omni antenna, and the one on the right is from a 15 dBi omni antenna. You can clearly see the flattening of the signal. It is very plausible that a higher-gain antenna, such the one on the right, could cause users on the floors above and below the antenna to lose their connection. Ultimately, when sticking with omni antennas, choosing between a higher gain and a lower gain is choosing between reaching people farther away horizontally (higher gain) or reaching people farther up or down vertically (lower gain). In many situations, you'll just have to place separate antennas on each floor of a multi floor installation to get the coverage you need.

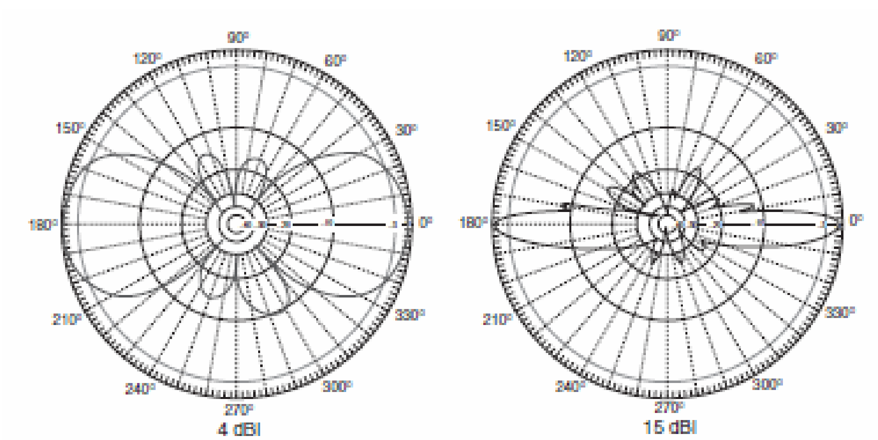


Figure 2.8: 4 dBi versus 15 dBi Elevation charts

2.2.3.3.2 Semi directional Antennas

Semi directional antennas are antennas that focus most of their energy in a particular direction. Examples include patch, panel, and Yagi antennas. (Yagi is pronounced *yah-gee.*) Patch and panel antennas come in flat enclosures and can be easily mounted on walls and Yagi antennas look a lot like TV antennas—a long rod with tines sticking out; however, the Yagi antennas are usually enclosed in a plastic casing that hides this appearance. Patch and panel antennas usually focus their energy in a horizontal arc of 180 degrees or less, whereas Yagi antennas usually have a coverage pattern of 90 degrees or less [4]. Figure 2.9 shows examples of patch, panel, and Yagi antennas. The Azimuth and Elevation charts for Yagi antennas often look the same. In other words, they often have the same coverage pattern from the top-down view (horizontal coverage) as they do from the side view (vertical coverage). Figure 2.10 shows an example coverage pattern of a 9 dBi Yagi antenna. Panel antennas usually have a similar pattern to Yagi antennas, except the "fish-like design" appears quite a bit fatter. Semi directional antennas are most useful for providing RF coverage down long hallways or corridors when using Yagi-style antennas and providing RF coverage in "one" direction when using patch or panel antennas. The patch and panel antennas will have some level of energy propagated behind their intended direction. (This energy is known as the rear lobe.) However, most of the energy will be directed inward. For this reason, patch and panel antennas are usually mounted on outside walls facing inward when they are intended to provide coverage inside an area only [4].

Figure 2.9: Examples of semi directional antennas

Additionally, they can be used on the outside of a building to create an "external-only" hotspot that is open to the public or possibly less secure than the internal network. Creatively using Yagi, patch, and panel antennas can prevent the use of large numbers of omni antennas for many situations. For example, a single patch antenna placed on a wall facing inward may provide all the coverage needed when two omni antennas would otherwise be needed. This is because the energy coming from the patch antenna is forced directionally inward instead of being forced in all horizontal directions. The RF energy is going where it is needed instead of losing 1/3 to 1/2 of it outside the walls of your facility [12].

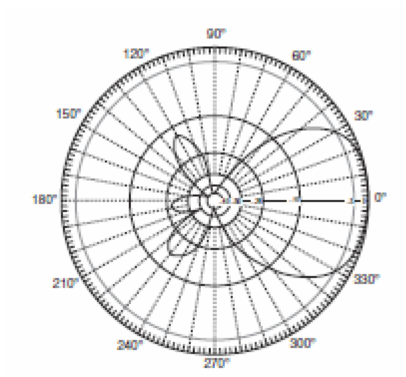


Figure 2.10: 9 dBi Yagi coverage pattern

2.2.3.3.3 Highly Directional Antennas

Highly directional antennas are antennas that transmit with a very narrow beam. These types of antennas often look like the satellite dish that is so popular in rural areas, such as where I grew up in West Virginia. They are generally called parabolic dish or grid antennas. The parabolic dish is the one that looks like a satellite dish, and the grid antenna looks like an antenna with a curved grill grate behind it. My explanations are somewhat simplified, but Figure 2.11 shows examples of each. Due to the high directionality of these antennas, they are mostly used for PtP or PtMP links (PtMP links will usually use an omni or semi directional antenna at the center and multiple highly directional or semi directional antennas at the remote sites). They can transmit at distances of 35 miles or more and usually require detailed aiming procedures that include a lot of trial and error. By positioning one antenna according to visual LOS and then making small movements at the other antenna, accurate alignment can usually be achieved.

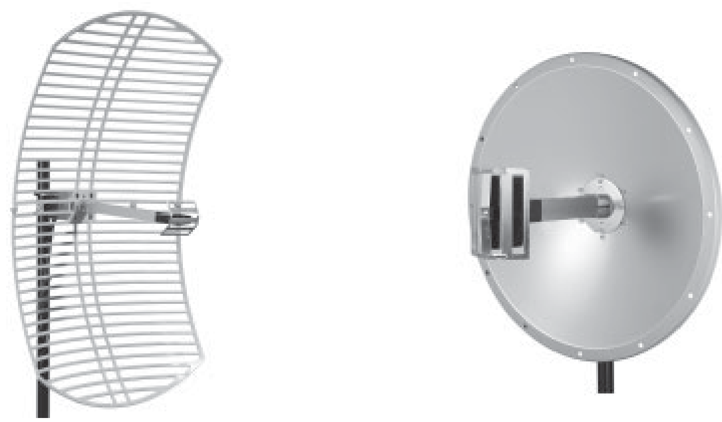


Figure 2.11: Parabolic dish and grid antennas

The grid antenna provides the added benefit of allowing air to pass through the back panels so that the antenna does not shift as much as the parabolic dish in high-wind scenarios [12].

Sectorized and Phased-Array Antennas

A sectorized antenna (or sector antenna) is a high-gain antenna that works back-to-back with other sectorized antennas. They are often mounted around a pole or mast and can provide coverage in indoor environments, such as warehouses, or outdoor environments, such as university campuses or hotspots. Figure 2.12 shows an example of sectorized antennas mounted on a pole [4].

A phased-array antenna is a special antenna system that is actually composed of multiple antennas connected to a single processor. The antennas are used to transmit different phases that result in a directed beam of RF energy aimed at client devices. Because phased-array antennas are specialized and expensive, they are not commonly used in the WLAN market.

Figure2.12: Sectorized antennas

2.2.3.3.4 Multiple-Input, Multiple-Output (MIMO) Antenna Systems

The final type of antenna system must be considered carefully at the time of this writing. The IEEE 802.11n amendment when ratified will use MIMO (pronounced my-moe) technology, but the exact implementation is still open for debate. However, certain vendors are releasing what they are calling “pre-n” equipment, and some of them are promising that their devices will be upgradable to the ratified IEEE 802.11n amendment through firmware. Depending on the processing power and memory requirements of the final IEEE 802.11n amendment, this may or may not be possible. Key factors will include the minimum number of antennas and the way those antennas are used in the final standard. For this reason, any device that states its data rate capabilities as greater than 54 Mbps, as of early 2007, may or may not be able to be upgraded to comply with the IEEE 80211n amendment [12].

MIMO, in its simplest description, is just the use of more than one antenna at the same time. This is different from antenna diversity as discussed earlier in this chapter because multiple antennas are actually used at the same time. With creative use of the antennas and changes in the underlying MAC layer of the IEEE 802.11 standard, bandwidth rates as high as 600 Mbps have been touted. Because the antennas used by MIMO devices are still standard antenna types connected to modern processing systems, MIMO will actually be addressed more in Chapters 3 and 4 where applicable.

2.2.3.4 Cells

A cell is the geographic unit of a cellular system. The cellular comes from a structure of small hexagonal cells which is divided from the covering region. Cells are base stations that transmitting over small areas which are represented by hexagon but the real shape is not the hexagon. Each cell shape or size depends on the landscape. The shape and size of the cell depends on several parameters such as ERP, antenna radiation patern and propagation environment.

2.2.3.4.1 Omni cell

The cell uses omni directional antenna is known as omni cell. An omni directional antenna is an antenna system which radiates power uniformly in one plane with a directive pattern shape in a perpendicular plane. This pattern is often described as "donut shaped". Omni directional antenna can be used to link multiple directional antennas in outdoor point to multipoint communication systems including cellular phone connections and TV broadcasts [1].

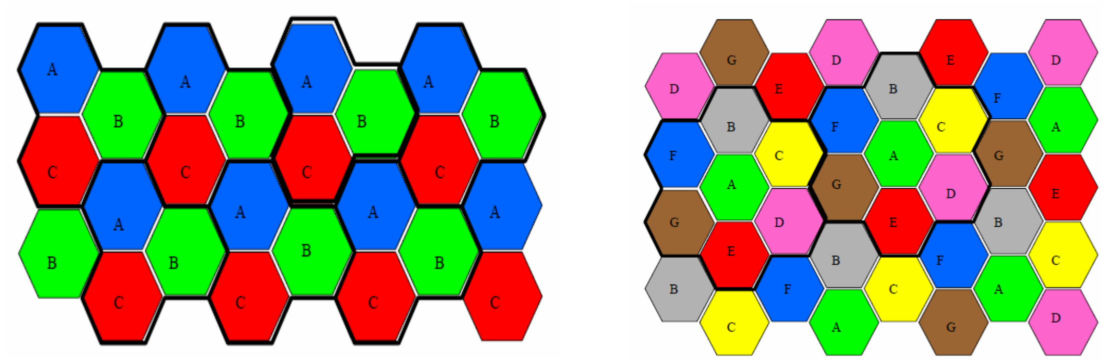
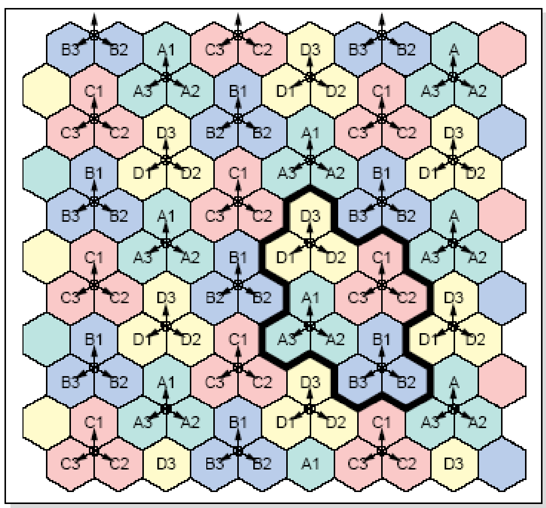


Figure 2.13: Frequency reuse factor 3 and 7 Omni cell configuration

2.2.3.4.2 Sectoring cell

Sectorization scheme is achieved by dividing a cell into number of sectors. It may 3sectors (120 degree), 4 sectors (90 degree), 6 sectors (60 degree) etc. each sector is treated as a logical omni cell, where directional antenna are used in each sector. Here the directional antenna may be semi directional or highly directional. Semi directional antennas are antennas that focus most of their energy in a particular direction. Examples include patch, panel, and Yagi antennas. Highly directional antennas are antennas that transmit with a very narrow beam. These types of antennas often look like the satellite dish. They are generally called parabolic dish or grid antennas. Due to the high directionality of these antennas, they are mostly used for PtP or PtMP links [4].



4/12 Cell Pattern

Figure 2.14: FRF 4 with 120 degree sectorization

2.2.3.5 Cell Cluster

A cluster is a group of cells. No channel reusing within a cluster. A cell cluster is a group of identical cell in which the entire available channel (Frequencies) is evenly distributed. The most widely used plan is N=7 cell cluster.

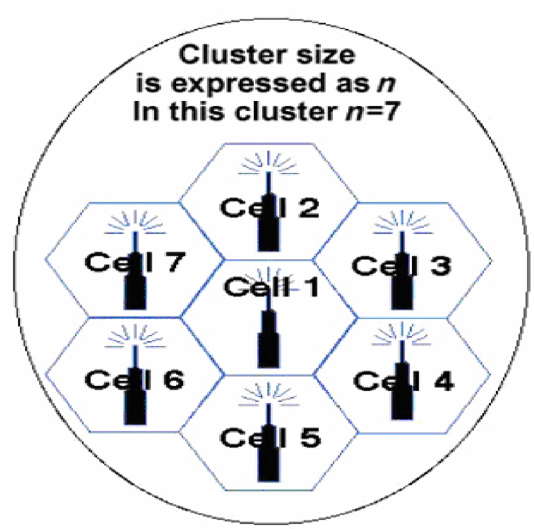


Figure 2.15: A seven cell cluster

2.2.3.6 Cell coverage

Cell coverage depends on user defined parameters such as Transmitting Power, antenna height, antenna gain, antenna location, and antenna directivity. Several other parameters such as propagation environment, hills, tunnels, foliage, and building greatly affect the RF coverage. These types of parameters are not user defined, vary from place to place, and are difficult to predict. As a result the practical cell is highly irregular in multipath environment.

1. Macrocells;
2. Microcells;
3. Picocells.
4. Umbrella cell

2.2.3.6.1 Macrocellular Radio Networks

Macrocells are mainly used to cover large areas with low traffic densities. These cells have radii between 1 and 10 km. A distinction between large macrocells and small macrocells should be made [4]. Large macrocells have radii between 5 and 10 km or even higher. They are used for rural areas. Small cells have radii between 1 and 5 km. These cells are used if the traffic density in large cells is so high that it will cause blocking of calls. They thus provide large cells with extra capacity (cell splitting). Planning small cells is more difficult because traffic predictions for relatively small areas cannot be easily done. The signals undergo multipath Rayleigh fading and lognormal shadowing. The standard deviation of lognormal shadowing signal lies between 4 and 12 dB. Typical root mean square (rms) delay spread is 8m s [14] .

2.2.3.6.2 Microcellular Radio Networks

Microcellular radio networks are used in areas with high traffic density, like (sub)urban areas. The cells have radii between 200m and 1 km. For such 20 Interference Analysis and Reduction for Wireless Systems small cells, it is hard to predict traffic densities and area coverage. Models for such parameters prove to be quite unreliable in practice. This is because the shape of the cell is time dynamic (i.e., the shape changes from time to time) due to propagation characteristics. We can distinguish one- and two-dimensional microcells. One-dimensional microcells are placed in a chainlike manner along main highways with high traffic densities, whereas ‘‘two dimensional’’ refers to the case where an antenna transmits the main ray and two additional rays are reflected off buildings on both sides of the street. One-dimensional microcells usually cover one or two house blocks. Antennas are placed at street lamp elevations. Surrounding buildings block signals propagating to adjacent cochannel cells. This improves the ability to reuse frequencies, as cochannel interference is reduced drastically by the shadowing effect caused by the infrastructure. Microcells follow a dual path-loss law. Violation of this law depends on the type of environment and the position of the transmitting antenna. The signal undergoes Rician fading and lognormal shadowing. Typical rms delay spread is 2 m s.

2.2.3.6.3 Picocellular Radio Networks

Picocells or indoor cells have cell radii between 10 and 200m. For indoor applications, cells have three-dimensional structures. Fixed cluster sizes, fixed channel allocations, and prediction of traffic densities are difficult for indoor applications. Today, picocellular radio systems are used for wireless office communications. and 4. We will also see, later on, how these characteristics influence the interference aspects. Path loss exponent varies from 1.2 to 6.8. Signals in picocells are always Rician faded. The Rician parameter lies between 6.8 and 11 dB. Typical values of rms delay spread lie between 50 and 300 m s. For more details the reader is referred to the three chapters that follow [13][14].

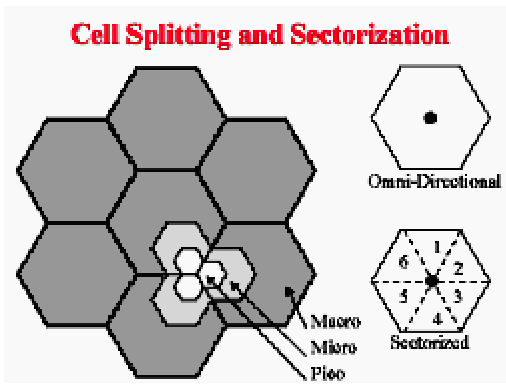


Figure 2.16: Illustration of Macro, Micro and Pico cell

2.2.3.6.4 Umbrella cell

By using different antenna heights (often on the same building ore tower) and different power labels, it is possible to provide "large" and "small" cells which are co-located with some smaller micro cells at a large location. This technique is called the umbrella cell approach.

It is used to provide large area coverage to high speed users while providing small area coverage to user traveling low speed. Following figure illustrates an umbrella cell which is co-located with some smaller micro cells [8].

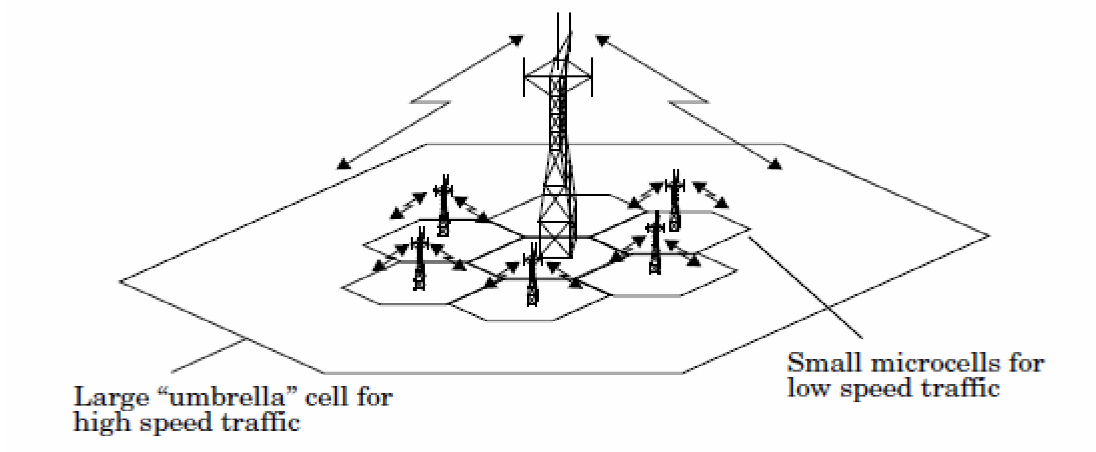


Figure 2.17: umbrella cell

2.2.3.7 Frequency Reuse

Because there is a small number of radio channel frequencies available for the systems, engineers have to find a way to reuse these channels for carrying more than one connection at a time. Frequency reuse is implemented by apply the cellular concept into the mobile telephone system. This concept is base on assigning a group of radio channels to each cell. Each cell is assigned different channels. The same group of channels can be used in different cells that are far enough from each other and their frequencies do not interfere [13].

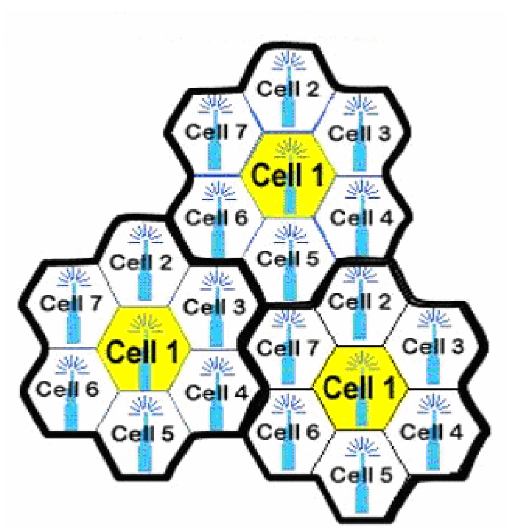


Figure 2.18: Frequency Reuse Factor 7

Cells with the same number have the same set of frequencies. According to the picture, the number of available frequencies is 7. Then each cell uses 1/7 of available cellular channels.

2.2.4 Mobile subscriber unit (MSU)

The mobile station represents the mobile network components. They consist of the mobile equipment (ME) and the subscriber identity module (SIM): MS = ME+SIM.

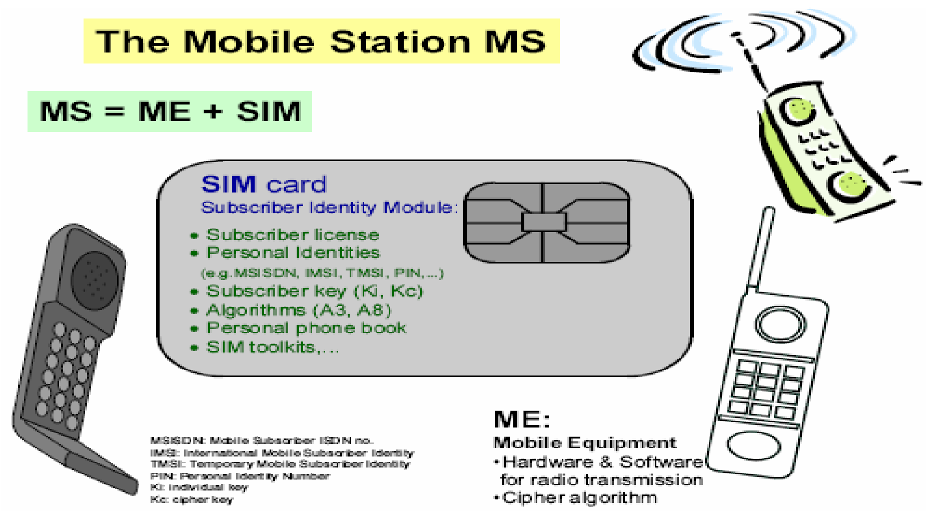


Figure 2.19: Mobile subscriber unit

2.2.4.1 The SIM card

The SIM consist of a microchip, which uses either a check card or a plate made of a synthetic material as a carrier. Without a SIM card, the use of an MS is normally not possible. An exception is the emergency call, which should always be possible with a functioning ME. The SIM card carriers the subscriber related information and codes, so that a GSM subscriber with a SIM card can use different ME [16]. The main task of the SIM is the storage of data: permanent and temporary administrative data as well as data concerning security. Personal telephone list may be stored and using the SIM toolkit with enhanced memory space, it is possible to enable applications such as mobile banking etc.

Important stored codes are:

- Personal Identity Number (PIN)
- PIN Unblocking Key (PUK)
- Mobile Station ISDN number (MSISDN)
- International Mobile Subscriber Identity (IMSI)
- Temporary Mobile Subscriber Identity (TMSI)

Important data relating to security are:

- Individual Key, Ki
- Cipher Key, Kc
- Algorithm for authentication and ciphering (A3,A8)

2.2.4.2 The Mobile Equipment (ME)

The Mo0bile Equipment unites the tasks of many functional elements of the fixed GSM-PLMN network. By using the data of the SIM card, the speech is digitalized, compressed, secured again loss of data (redundancy + interleaving), encrypted to prevent interception and modulated onto the RF created by the mobile station. Directly after, the signal is amplified and transmitted. In the opposite direction, the process runs inversely, beginning with the reception of the RF[16].

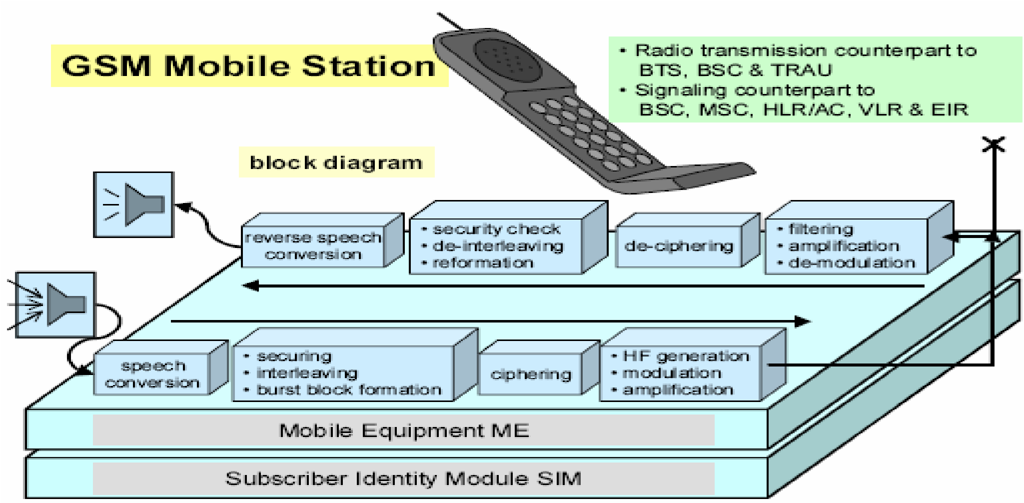


Figure 2.20: Function of Mobile Equipment

Chapter 3
Analog and Digital Cellular System

3.1 Introduction

Late 1970s, analog cellular system was introduced in many countries of the world. 1G are considered as analog cellular system while 2G and 3G are considered as digital cellular system. In this chapter we discussed about Multiple Access Techniques for both analog and digital cellular system.

3.2 Analog Cellular Communication System

Analog cellular network is the 1st generation (1G) cellular communication system. The design of the voice communication of this generation was made with analog signals. Two types of analog cellular networks are

- Advanced Mobile phone System (AMPS)
- Total Access Communication system(TACS)

Advanced Mobile phone System (AMPS) is one of the earliest commercial cellular communication systems. AMPS technology is currently deployed throughout North America and AMPS derivative systems are deployed in a many of worldwide cellular markets. Generally AMPS operates in ISM 800 MHz band and uses FM and FSK for modulation. AMPS is an analog cellular system using FDMA [15].

Total Access Communication system (TACS) is the European version of AMPS.A typical TACS system operates in 450 MHz and 900 MHz band.

3.2.1 Analog cellular Multiple Access Technique (FDMA)

Frequency Division Multiple Access or FDMA is a channel access method used in multiple-access protocols as a channelization protocol. FDMA gives users an individual allocation of one or several frequency bands, or channels. Multiple Access systems coordinate access between multiple users. The users may also share access via different methods such as TDMA, CDMA, or SDMA. These protocols are utilized differently, at different levels of the theoretical OSI model.

FDMA gives users an individual allocation of one or several frequency bands, or channels. Meaning of FDMA - "Frequency Division Multiple Access", is the division of the frequency band allocated for wireless cellular telephone communication into many channels, each of which can carry a voice conversation or, with digital service, carry digital data. FDMA is a basic technology in the analog Advanced Mobile Phone Service (AMPS), the most widely-installed cellular phone system installed in North America. With FDMA, each channel can be assigned to only one user at a time. FDMA is also used in the Total Access Communication System (TACS).

In FDMA, each transmitter is assigned a distinct frequency channel so that receivers can discriminate among them by tuning to the desired channel. TDMA and CDMA are always used in combination with FDMA [10].

Disadvantage: Crosstalk which causes interference on the other frequency and may disrupt the transmission.

Features:

- FDMA requires high-performing filters in the radio hardware, in contrast to TDMA and CDMA
- FDMA is not vulnerable to the timing problems that TDMA has. Since a predetermined frequency band is available for the entire period of communication, stream data (a continuous flow of data that may not be packetized) can easily be used with FDMA.
- Due to the frequency filtering, FDMA is not sensitive to near-far problem which is pronounced for CDMA.
- Each user transmits and receives at different frequencies as each user gets a unique frequency slot

It is important to distinguish between FDMA and frequency-division duplexing (FDD). While FDMA allows multiple users simultaneous access to a certain system, FDD refers to how the radio channel is shared between the uplink and downlink (for instance, the traffic going back and forth between a mobile-phone and a base-station). Furthermore, frequency-division multiplexing (FDM) should not be confused with FDMA. The former is a physical layer technique that combines and transmits low-bandwidth channels through a high-bandwidth channel. FDMA, on the other hand, is an access method in the data link layer [10].

FDMA also supports demand assignment in addition to fixed assignment. Demand assignment allows all users apparently continuous access of the radio spectrum by assigning carrier frequencies on a temporary basis using a statistical assignment process.

3.3 Digital Cellular Communication System

In order to provide higher quality and less noise prone mobile voice communications, the second generation of cellular phone network was developed. While the 1st generation was designed for analog voice communication, the second generation was mainly designed for digitized voice.

Five major systems for digital cellular systems are:

- Digital Advanced Mobile phone System (D-AMPS)
- Global System for Mobile Communication (GSM)
- Code Division Multiple Access (CDMA)
- General Packet Radio System (GPRS)
- Personal Communication System (PCS)

3.3.1 Digital cellular Multiple Access Techniques

Two Important Digital Multiple techniques are

- Time division multiple access (TDMA)
- Code division multiple access (CDMA)

3.3.1.1Time division multiple access (TDMA)

Time division multiple access (TDMA) is a channel access method for shared medium networks. It allows several users to share the same frequency channel by dividing the signal into different time slots. The users transmit in rapid succession, one after the other, each using his own time slot [10].

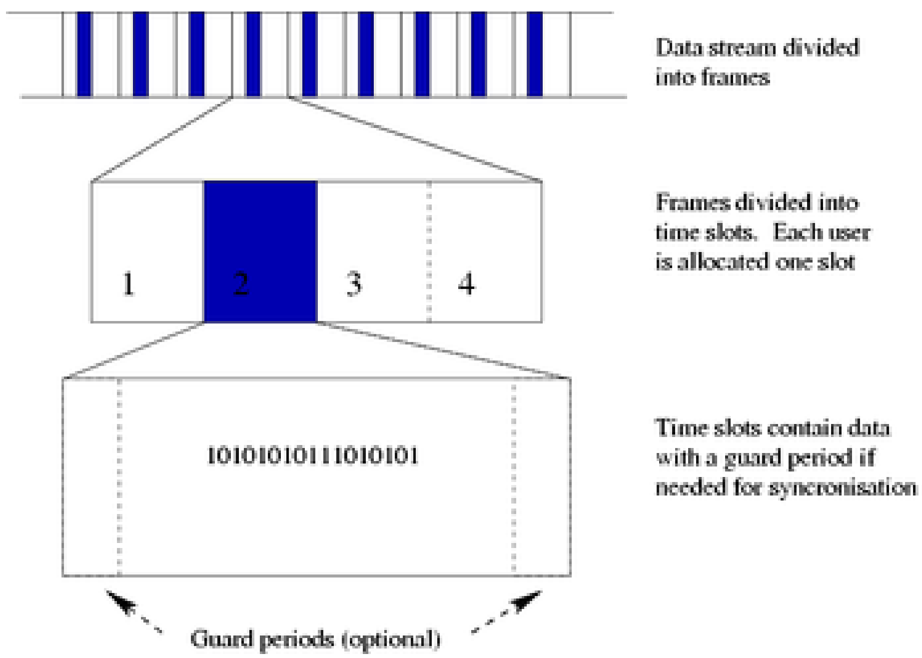


Figure 3.1: TDMA Technique

This allows multiple stations to share the same transmission medium (e.g. radio frequency channel) while using only a part of its channel capacity. TDMA is used in the digital 2G cellular systems such as Global System for Mobile Communications (GSM), IS-136, Personal Digital Cellular (PDC) and iDEN, and in the Digital Enhanced Cordless Telecommunications (DECT) standard for portable phones. It is also used extensively in satellite systems, and combat-net radio systems. For usage of Dynamic TDMA packet mode communication, see below. TDMA frame structure showing a data stream divided into frames and those frames divided into time slots [10].

TDMA is a type of Time-division multiplexing, with the special point that instead of having one transmitter connected to one receiver, there are multiple transmitters. In the case of the uplink from a mobile phone to a base station this becomes particularly difficult because the mobile phone can move around and vary the timing advance required to make its transmission match the gap in transmission from its peers.

TDMA characteristics

- Shares single carrier frequency with multiple users
- Non-continuous transmission makes handoff simpler
- Slots can be assigned on demand in dynamic TDMA
- Less stringent power control than CDMA due to reduced intra cell interference
- Higher synchronization overhead than CDMA
- Advanced equalization may be necessary for high data rates if the channel is "frequency selective" and creates Inter symbol interference
- Cell breathing (borrowing resources from adjacent cells) is more complicated than in CDMA
- Frequency/slot allocation complexity
- Pulsating power envelop: Interference with other devices

TDMA in mobile phone systems

2G systems

Most 2G cellular systems, with the notable exception of IS-95, are based on TDMA. GSM, D-AMPS, PDC, iDEN, and PHS are examples of TDMA cellular systems. GSM combines TDMA with Frequency Hopping and wideband transmission to reduce interference; this minimizes common types of interference.

In the GSM system, the synchronization of the mobile phones is achieved by sending timing advance commands from the base station which instructs the mobile phone to transmit earlier and by how much. This compensates for the propagation delay resulting from the light speed velocity of radio waves. The mobile phone is not allowed to transmit for its entire time slot, but there is a guard interval at the end of each time slot. As the transmission moves into the guard period, the mobile network adjusts the timing advance to synchronize the transmission.

Initial synchronization of a phone requires even more care. Before a mobile transmits there is no way to actually know the offset required. For this reason, an entire time slot has to be dedicated to mobiles attempting to contact the network (known as the RACH in *GSM*). The mobile attempts to broadcast at the beginning of the time slot, as received from the network. If the mobile is located next to the base station, there will be no time delay and this will succeed. If, however, the mobile phone is at just less than 35 km from the base station, the time delay will mean the mobile's broadcast arrives at the very end of the time slot. In that case, the mobile will be instructed to broadcast its messages starting nearly a whole time slot earlier than would be expected otherwise. Finally, if the mobile is beyond the 35 km cell range in GSM, then the RACH will arrive in a neighboring time slot and be ignored. It is this feature, rather than limitations of power, that limits the range of a GSM cell to 35 km when no special extension techniques are used. By changing the synchronization between the uplink and downlink at the base station, however, this limitation can be overcome [10].

3G systems

Although most major 3G systems are primarily based upon CDMA, time division duplexing (TDD), packet scheduling (dynamic TDMA) and packet oriented multiple access schemes are available in 3G form, combined with CDMA to take advantage of the benefits of both technologies.

While the most popular form of the UMTS 3G system uses CDMA and frequency division duplexing (FDD) instead of TDMA, TDMA is combined with CDMA and Time Division Duplexing in two standard UMTS UTRA modes, UTRA TDD-HCR (better known as TD-CDMA), and UTRA TDD-LCR (better known as TD-SCDMA). In each mode, more than one handset may share a single time slot. UTRA TDD-HCR is used most commonly by UMTS-TDD to provide Internet access, whereas UTRA TDD-LCR provides some interoperability with the forthcoming Chinese 3G standard.

3.3.1.2 Code division multiple access (CDMA)

Code division multiple access (CDMA) is a channel access method used by various radio communication technologies. It should not be confused with the mobile phone standards called cdmaOne and CDMA2000 (which are often referred to as simply *CDMA*), which use CDMA as an underlying channel access method.

One of the basic concepts in data communication is the idea of allowing several transmitters to send information simultaneously over a single communication channel. This allows several users to share a band of frequencies (see bandwidth). This concept is called multiplexing. CDMA employs spread-spectrum technology and a special coding scheme (where each transmitter is assigned a code) to allow multiple users to be multiplexed over the same physical channel. By contrast, time division multiple access (*TDMA*) divides access by time, while frequency-division multiple access (*FDMA*) divides it by frequency. CDMA is a form of spread-spectrum signaling, since the modulated coded signal has a much higher data bandwidth than the data being communicated.

Steps in CDMA Modulation

CDMA is a spread spectrum multiple access technique. A spread spectrum technique spreads the bandwidth of the data uniformly for the same transmitted power. Spreading code is a pseudorandom code that has a narrow Ambiguity function, unlike other narrow pulse codes. In CDMA a locally generated code runs at a much higher rate than the data to be transmitted. Data for transmission is simply logically XOR (exclusive OR) added with the faster code. The figure shows how spread spectrum signal is generated. The data signal with pulse duration of T_b is XOR added with the code signal with pulse duration of T_c. (Note: bandwidth is proportional to $1 / T$ where T = bit time) Therefore, the bandwidth of the data signal is $1 / T_b$ and the bandwidth of the spread spectrum signal is $1 / T_c$. Since T_c is much smaller than T_b, the bandwidth of the spread spectrum signal is much larger than the bandwidth of the original signal. The ratio T_b / T_c is called spreading factor or processing gain and determines to a certain extent the upper limit of the total number of users supported simultaneously by a base station [10].

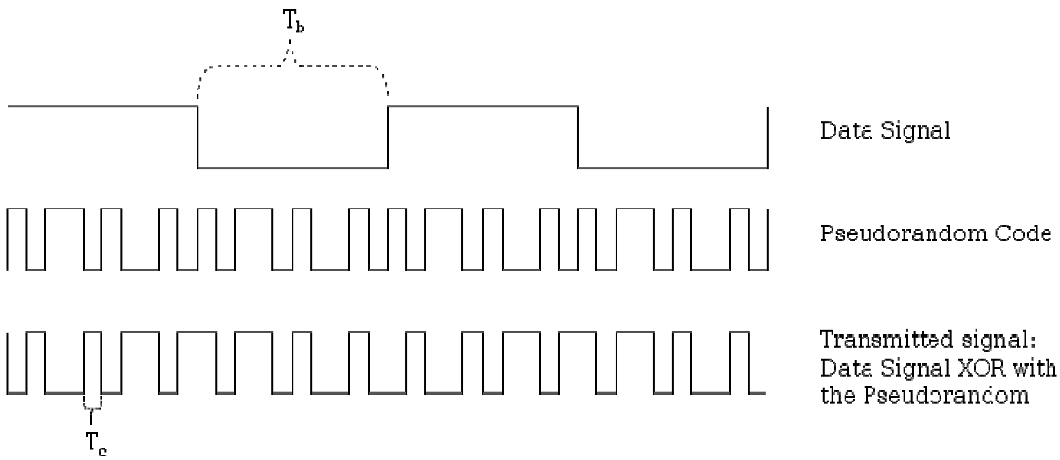


Figure 3.2: CDMA Signal Generation

Each user in a CDMA system uses a different code to modulate their signal. Choosing the codes used to modulate the signal is very important in the performance of CDMA systems. The best performance will occur when there is good separation between the signal of a desired user and the signals of other users. The separation of the signals is made by correlating the received signal with the locally generated code of the desired user. If the signal matches the desired user's code then the correlation function will be high and the system can extract that signal. If the desired user's code has nothing in common with the signal the correlation should be as close to zero as possible (thus eliminating the signal); this is referred to as cross correlation. If the code is correlated with the signal at any time offset other than zero, the correlation should be as close to zero as possible. This is referred to as auto-correlation and is used to reject multi-path interference [10].

In general, CDMA belongs to two basic categories: synchronous (orthogonal codes) and asynchronous (pseudorandom codes).

Chapter 4
Capacity Enhancement and Handoff

4.1 Introduction

The motivation behind implementing a cellular mobile system is to improve the utilization of spectrum efficiency. Frequency reuse scheme is one of the concept, another important concept are discussed here. They are cell splitting, sectoring, and zone micro cell. It is to be noted that with the increasing capacity, handoff increases. Several types of handoff also described in this chapter.

4.2 Capacity Enhancement Techniques

As the demand for wireless service increases, the number of channels assigned to a cell eventually becomes insufficient to support the required number of users. At this point, cellular design techniques are needed to provide more channels per unit coverage area. Techniques such as cell splitting, sectoring, and coverage zone approaches are used in practice to expand the capacity of cellular systems. Cell splitting allows an orderly growth of the cellular system. Sectoring uses directional antennas to further control the interference and frequency reuse of channels. The zone microcell concept distributes the coverage of a cell and extends the cell boundary to hardto- reach places. While cell splitting increases the number of base stations in order to increase capacity, sectoring and zone microcells rely on base station antenna placements to improve capacity by reducing co-channel interference. Cell splitting and zone microcell techniques do not suffer the trunking inefficiencies experienced by sectored cells, and enable the base station to oversee all handoff chores related to the microcells, thus reducing the computational load at the MSC. These three popular capacity improvement techniques will be explained in detail.

Accept frequency reuse technique other capacity inhancement technics are

- Cell Splitting
- Sectoring
- Zone micro cell

4.2.1 Cell Splitting

It is the process of subdividing a congestive cell into smaller cells, each with its own basic station and corresponding reduction of antenn hight and transmitter power. Usually the new radius is one half the original radius. Cell splitting increases the capacity of a cellular system since it increases the number of times that chan- nels are reused. By defining new cells which have a smaller radius than the original cells and by installing these smaller cells (called microcells) between the existing cells, capacity increases due to the additional number of channels per unit area. Imagine if every were reduced in such a way that the radius of every cell was cut in half. In order to cover the entire service area with smaller cells, approximately four times as many cells would be required. This can be easily shown by considering a circle with radius R. The area covered by such a circle is four times as large as the area covered by a circle with radius R/2. The increased number of cells would increase the number of clusters over the coverage region, which in turn would increase the number of channels, and thus capacity, in the coverage area. Cell splitting allows a system to grow by replacing large cells with smaller cells, while not upsetting the channel allocation scheme required to maintain the minimum co-channel reuse ratio Q between co-channel cells. An example of cell splitting is shown in Figure 4.1. In Figure 4.1, the base stations are placed at corners of the cells, and the area served by base station A is assumed to be saturated with traffic (i.e., the blocking of base station A exceeds acceptable rates). New base stations are therefore needed in the region to increase the number of channels in the area and to reduce the area served by the single base station. Note in the figure that the original base station A has been surrounded by six new microcells. In the example shown in Figure 4.1, the smaller cells were added in such a way as to preserve the frequency reuse plan of the system. For example, the microcell base station labeled G was placed half way between two larger stations utilizing the same channel set G. This is also the case for the other microcells in the figure. As can be seen from Figure 4.1, cell splitting merely scales the geometry of the cluster. In this case, the radius of each new microcell is half that of the original cell.

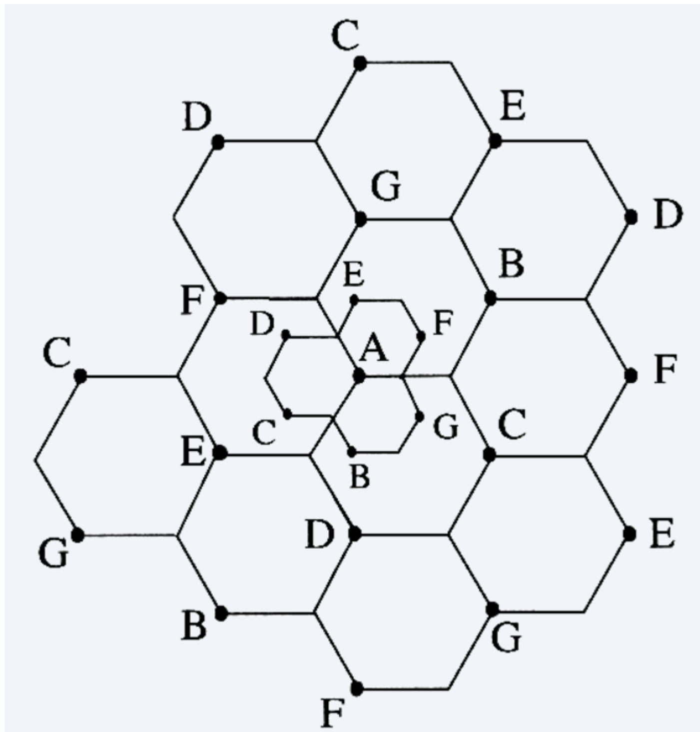


Figure 4.1: Illustration of cell splitting.

For the new cells to be smaller in size, the transmit power of these cells must be reduced. The transmit power of the new cells with radius half that of the original cells can be found by examining the received power *Pr* at the new and old cell boundaries and setting them equal to each other. This is necessary to ensure that the frequency reuse plan for the new microcells behaves exactly as for the original cells. For Figure 3.8

$$P_r \text{ [at old cell boundary] } \infty\, P_{t1} R^{-n}$$

and

$$P_r \text{ [at new cell boundary] } \infty\, P_{t2} (R/2)^{-n}$$

where $Pt1$ and $Pt2$ are the transmit powers of the larger and smaller cell base stations, respectively, and n is the path loss exponent. If we take $n = 4$ and set the received powers equal to each other, then

$$Pt2 = Pt1/16$$

In other words, the transmit power must be reduced by 12 dB in order to fill in the original coverage area with microcells, while maintaining the S/I requirement. In practice, not all cells are split at the same time. It is often difficult for service providers to find real estate that is perfectly situated for cell splitting. Therefore, different cell sizes will exist simultaneously. In such situations, special care needs to be taken to keep the distance between cochannel cells at the required minimum, and hence channel assignments become more complicated [8]. Also, handoff issues must be addressed so that high speed and low speed traffic can be simultaneously accommodated. When there are two cell sizes in the same region as shown in Figure 4.1. If the larger transmit power is used for all cells, some channels used by the smaller cells would not be sufficiently separated from co-channel cells. On the other hand, if the smaller transmit power is used for all the cells, there would be parts of the larger cells left unserved. For this reason, channels in the old cell must be broken down into two channel groups, one that corresponds to the smaller cell reuse requirements and the other that corresponds to the larger cell reuse requirements. The larger cell is usually dedicated to high speed traffic so that handoffs occur less frequently. The two channel group sizes depend on the stage of the splitting process. At the beginning of the cell splitting process, there will be fewer channels in the small power groups. However, as demand grows, more channels will be required, and thus the smaller groups will require more channels. This splitting process continues until all the channels in an area are used in the lower power group, at which point cell splitting is complete within the region, and the entire system is rescaled to have a smaller radius per cell. Antenna downtilting, which deliberately focuses radiated energy from the base station toward the ground (rather than toward the horizon), is often used to limit the radio coverage of newly formed microcells.

Example

Assume each BS uses 60 channels and large cell radius of 1 km and microcell radius of 0.5 km. Find the number of channels in a 3 km by 3 km square around A when (a) without the use of microcells (b) the labeled microcells are used (c) all original BS are replaced by microcells.

Solution:

(a) 5×60 = 300 (b) (5+6)×60 = 660

(2.2x) (c) (5+12)×60 = 1020 (3.4x)

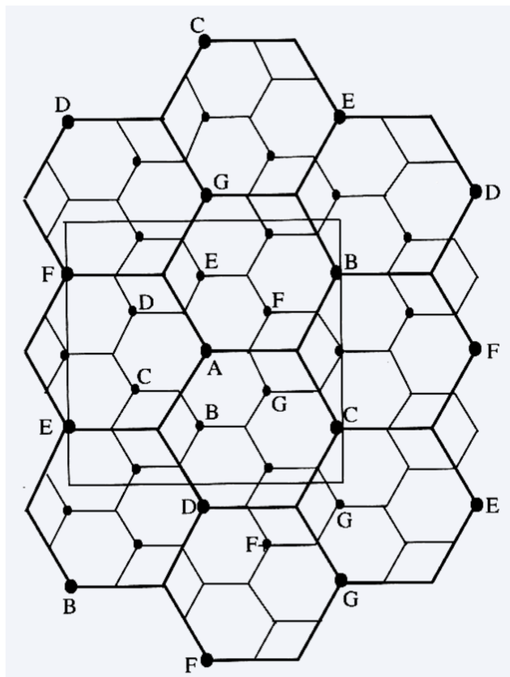


Figure 4.2: Illustration of cell splitting within a 3 km by 3 km square centered around base station A.

4.2.1.1 Types of splitting

There are two types of cell splitting techniques:

1. Permanent splitting
2. Dynamic splitting

4.2.1.1.1Permanent splitting

Installation of new cells has to be planned ahead of time, number of channels, transmitted power, assigned frequencies, cell-site selection etc. When ready, the actual service cut over should be set at the lowest traffic point, usually at midnight on a weekend. Assuming that the down time of the system is maximum 2 hours.

4.2.1.1.2 Dynamic splitting

This scheme is based on utilizing the allocated spectrum efficiency in real time. The algorithm for dynamically splitting cell sites is a tedious job since we cannot afford to have one single cell unused during cell splitting at heavy traffic hours.

4.2.1.2 Effect on splitting

When the cell splitting is occurring, in order to maintain the frequency-reuse distance ratio q in a system, there are two considerations.

1. Cells splitting affect the neighboring cells. Splitting cells causes an unbalanced situation in power and frequency-reuse distance and makes it necessary to split small cells in the neighboring cells. This phenomenon is the same as a ripple effect.
2. Certain channels should be used as barriers. To the same extent, large and small cells can be isolated by selecting a group of frequencies which will be used only in the cells on the other aide, in order to eliminate the interference being transmitted from the large cells to the small cells.

4.2.2 Sectoring

Cell splitting achieves capacity improvement by essentially rescaling the system. By decreasing the cell radius R and keeping the co-channel reuse ratio D/R unchanged, cell splitting increases the number of channels per unit area.

However, another way to increase capacity is to keep the cell radius unchanged and seek methods to decrease the D/R ratio. As we now show, sectoring increases SIR so that the cluster size may be reduced. In this approach, first the SIR is improved using directional antennas, and then capacity improvement is achieved by reducing the number of cells in a cluster, thus increasing the frequency reuse. However, in order to do this successfully, it is necessary to reduce the relative interference without decreasing the transmit power.

The co-channel interference in a cellular system may be decreased by replacing a single Omni directional antenna at the base station by several directional antennas, each radiating within a specified sector. By using directional antennas, a given cell will receive interference and transmit with only a fraction of the available co-channel cells. The technique for decreasing co-channel interference and thus increasing system performance by using directional antennas is called sectoring. The factor by which the co-channel interference is reduced depends on the amount of sectoring used. A cell is normally partitioned into three 120° sectors or six 60° sectors as shown in Figure 4.3 (a) and (b).

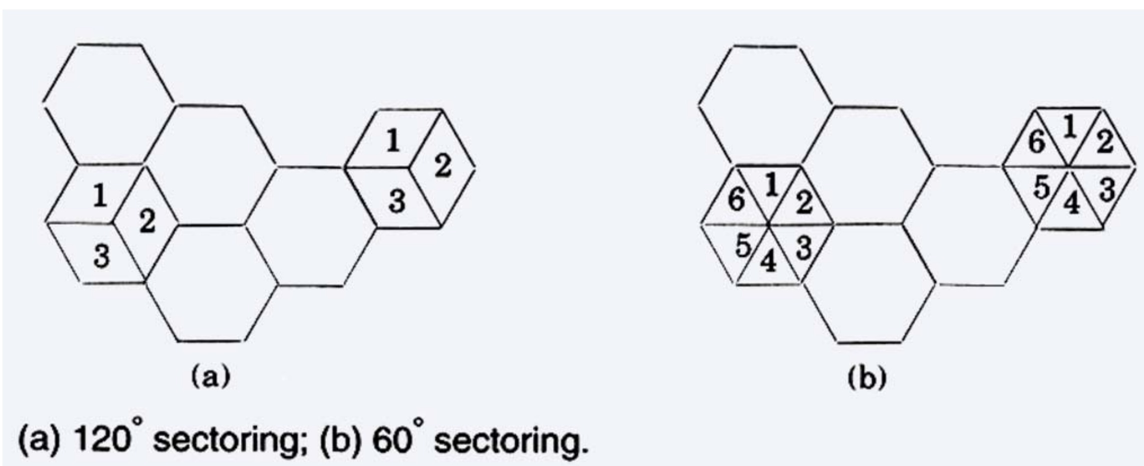


Figure 4.3: Illustration of 60° and 120° sectoring cell

When sectoring is employed, the channels used in a particular cell are broken down into sectored groups and are used only within a particular sector, as illustrated in Figure 4.3(a) and (b). Assuming seven-cell reuse, for the case of 120° sectors, the number of interferers in the first tier is reduced from six to two. This is because only two of the six co-channel cells receive interference with a particular sectored channel group. Referring to Figure 4.4, consider the interference experienced by a mobile located in the right-most sector in the center cell labeled “5”. There are three cochannel cell sectors labeled “5” to the right of the center cell, and three to the left of the center cell. Out of these six co-channel cells, only two cells have sectors with antenna patterns which radiate into the center cell, and hence a mobile in the center cell will experience interference on the forward link from only these two sectors. The resulting *S*/*I* for this case to be 24.2 dB, which is a significant improvement over the omnidirectional, where the worst case *S*/*I* was shown to be 17 dB. This *S*/*I* improvement allows the wireless engineer to then decrease the cluster size *N* in order to improve the frequency reuse, and thus the system capacity. In practical systems, further improvement in *S*/*I* is achieved by downtilting the sector antennas such that the radiation pattern in the vertical (elevation) plane has a notch at the nearest co-channel cell distance.

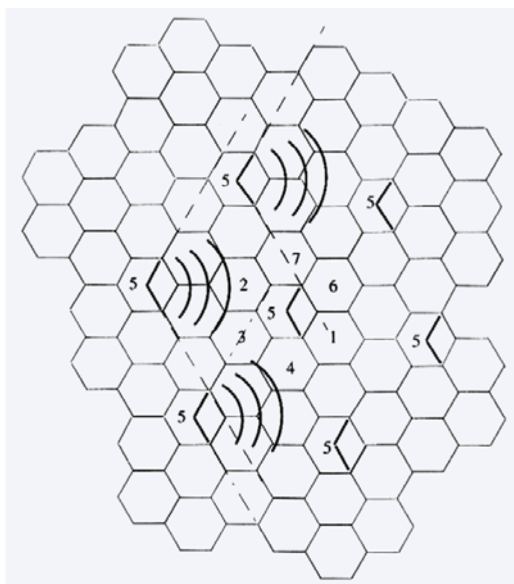


Figure 4.4: Illustration of how 120° sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only two of them interfere with the center cell. If omnidirectional antennas were used at each base station, all six co-channel cells would interfere with the center cell.

The improvement in *S*/*I* implies that with 120° sectoring, the minimum required *S*/*I* of 18 dB can be easily achieved with seven-cell reuse, as compared to 12-cell reuse for the worst possible situation in the unsectored case. Thus, sectoring reduces interference, which amounts to an increase in capacity by a factor of 12/7, or 1.714. In practice, the reduction in interference offered by sectoring enable planners to reduce the cluster size N, and provides an additional degree of freedom in assigning channels. The penalty for improved S/I and the resulting capacity improvement from the shrinking cluster size is an increased number of antennas at each base station, and a decrease in trunking efficiency due to channel sectoring at the base station. Since sectoring reduces the coverage area of a particular group of channels, the number of handoffs increases, as well. Fortunately, many modern base stations support sectorization and allow mobiles to be handed off from sector to sector within the same cell without intervention from the MSC, so the handoff problem is often not a major concern. It is the loss of traffic due to decreased trunking efficiency that causes some operators to shy away from the sectoring approach, particularly in dense urban areas where the directional antenna patterns are somewhat ineffective in controlling radio propagation. Because sectoring uses more than one antenna per base station, the available channels in the cell must be subdivided and dedicated to a specific antenna. This breaks up the available trunked channel pool into several smaller pools, and decreases trunking efficiency.

4.2.3 A Microcell Zone Concept

The increased number of handoffs required when sectoring is employed results in an increased load on the switching and control link elements of the mobile system. A solution to this problem was presented by Lee [14]. This proposal is based on a microcell concept for seven cell reuse, as illustrated in Figure 4.5. In this scheme, each of the three (or possibly more) zone sites (represented as Tx/Rx in Figure 4.5) are connected to a single base station and share the same radio equipment. The zones are connected by coaxial cable, fiber optic cable, or microwave link to the base station. Multiple zones and a single base station make up a cell. As a mobile travels within the cell, it is served by the zone with the strongest signal. This approach is superior to sectoring since antennas are placed at the outer edges of the cell, and any base station channel may be assigned to any zone by the base station. As a mobile travels from one zone to another within the cell, it retains the same channel. Thus, unlike in sectoring, a handoff is not required at the MSC when the mobile travels between zones within the cell. The base station simply switches the channel to a different zone site. In this way, a given channel is active only in the particular zone in which the mobile is traveling, and hence the base station radiation is localized and interference is reduced. The channels are distributed in time and space by all three zones and are also reused in co-channel cells in the normal fashion. This technique is particularly useful along highways or along urban traffic corridors. The advantage of the zone cell technique is that while the cell maintains a particular coverage radius, the co-channel interference in the cellular system is reduced since a large central base station is replaced by several lower powered transmitters (zone transmitters) on the edges of the cell. Decreased co-channel interference improves the signal quality and also leads to an increase in capacity without the degradation in trunking efficiency caused by sectoring. As mentioned earlier, an S/I of 18 dB is typically required for satisfactory system performance in narrowband FM. For a system with N = 7, a D/R of 4.6 was shown to achieve this.

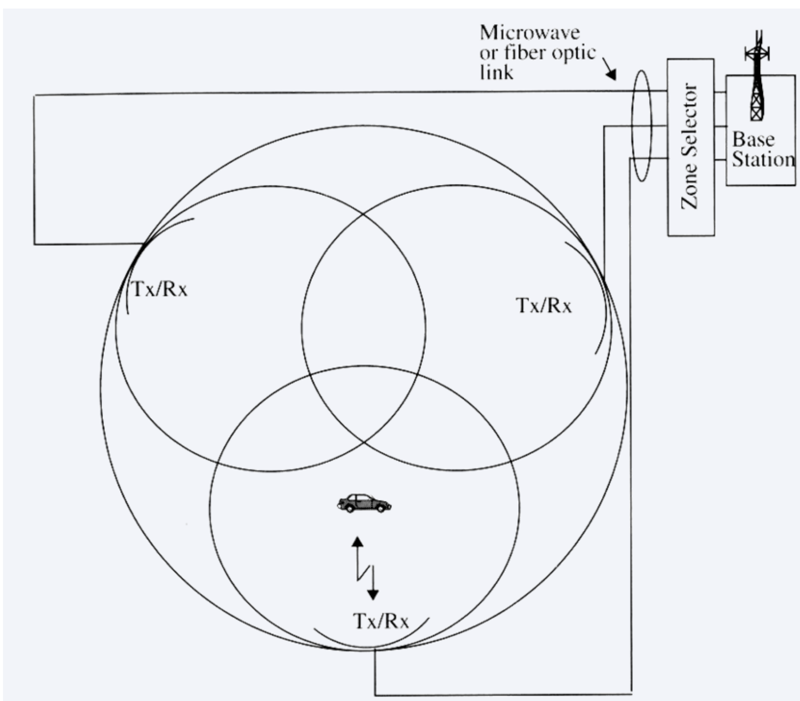


Figure 4.5: The microcell zone concept

With respect to the zone microcell system, since transmission at any instant is confined to a particular zone, this implies that a Dz /Rz of 4.6 (where Dz is the minimum distance between active co-channel zones and Rz is the zone radius) can achieve the required link performance. In Figure 4.6, let each individual hexagon represents a zone, while each group of three hexagons represents a cell. The zone radius Rz is approximately equal to one hexagon radius. Now, the capacity of the zone microcell system is directly related to the distance between co-channel cells, and not zones. This distance is represented as D in Figure 4.6. For a Dz /Rz value of 4.6, it can be seen from the geometry of Figure 4.6 that the value of co-channel reuse ratio, D/R, is equal to three, where R is the radius of the cell and is equal to twice the length of the hexagon radius. D/R = 3 corresponds to a cluster size of N = 3. This reduction in the cluster size from N = 7 to N = 3 amounts to a 2.33 times increase in capacity for a system completely based on the zone microcell concept. Hence for the same S/I requirement of 18 dB, this system provides a significant increase in capacity over conventional cellular planning. The exact worst case S/I of the zone microcell system can be estimated to be 20 dB. Thus, in the worst case, the system provides a margin of 2 dB over the required signal-to-interference ratio while increasing the capacity by 2.33 times over a conventional seven-cell system using omnidirectional antennas. No loss in trunking efficiency is experienced. Zone cell architectures are being adopted in many cellular and personal communication systems.

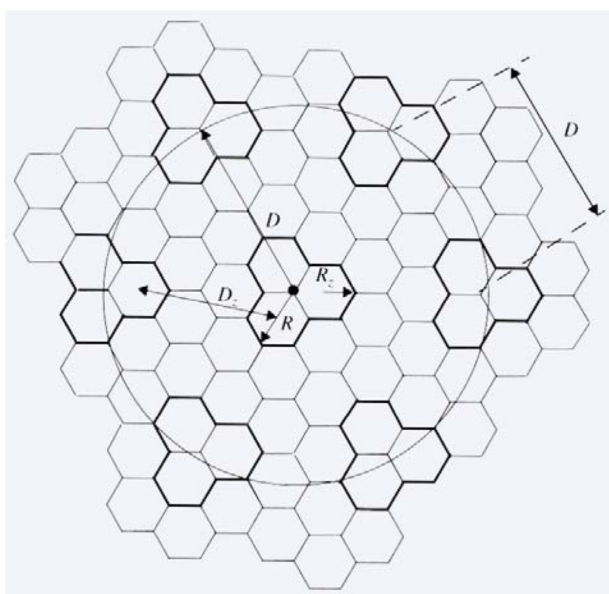


Figure 4.6: Define D, Dz , R, and Rz for a microcell architecture with N = 7. The smaller hexagons form zones and three hexagons (outlined in bold) together form a cell. Six nearest co-channel cells are shown.

4.3 Coverage improvement by Repeaters for Range Extension

Often a wireless operator needs to provide dedicated coverage for hard-to-reach areas, such as within buildings, or in valleys or tunnels. Radio retransmitters, known as repeaters, are often used to provide such range extension capabilities. Repeaters are bidirectional in nature, and simultaneously send signals to and receive signals from a serving base station. Repeaters work using over-the-air signals, so they may be installed anywhere and are capable of repeating an entire cellular or PCS band. Upon receiving signals from a base station forward link, the repeater amplifies and reradiates the base station signals to the specific coverage region. Unfortunately, the received noise and interference is also reradiated by the repeater on both the forward and reverse link, so care must be taken to properly place the repeaters, and to adjust the various forward and reverse link amplifier levels and antenna patterns. Repeaters can be easily thought of as bidirectional "bent pipes" that retransmit what has been received.

In practice, directional antennas or distributed antenna systems (DAS) are connected to the inputs or outputs of repeaters for localized spot coverage, particularly in tunnels or buildings. By modifying the coverage of a serving cell, an operator is able to dedicate a certain amount of the base station's traffic for the areas covered by the repeater. However, the repeater does not add capacity to the system—it simply serves to reradiate the base station signal into specific locations. Repeaters are increasingly being used to provide coverage into and around buildings, where coverage has been traditionally weak, many carriers have opted to provide in-building wireless penetration by installing microcells outside of large buildings, and then installing many repeaters with DAS networks within the buildings. This approach provides immediate coverage into targeted areas, but does not accommodate the increases in capacity that will arise due to increased outdoor and indoor user traffic. Eventually, dedicated base stations within buildings will be needed to accommodate the large number of in-building cellular users. Determining the proper location for repeaters and distributed antenna systems within buildings requires careful planning, particularly due to the fact that interference levels are reradiated into the building from the base station and from the interior of the building back to the base station.

Also, repeaters must be provisioned to match the available capacity from the serving base station. Fortunately, software products, such as SitePlanner, allow engineers to rapidly determine the best placements for repeaters and the required DAS network while simultaneously computing the available traffic and associated cost of the installation. SitePlanner is protected by US Patent 6,317,599 and other patents. Using SitePlanner, engineers can very quickly determine the proper provisioning for a particular level of range extension.

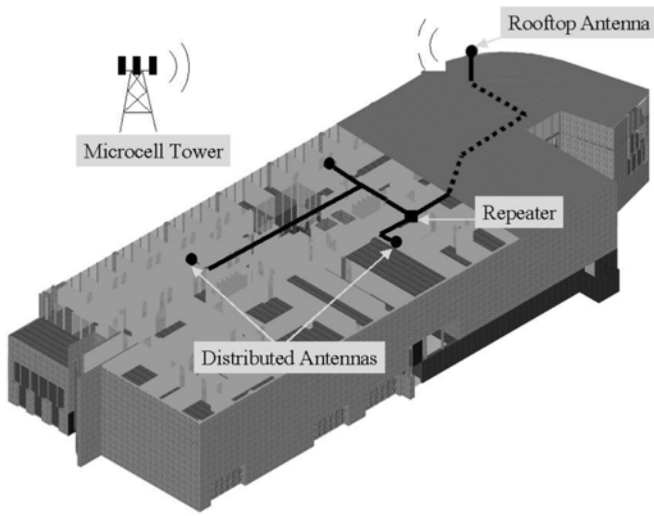


Figure 4.7: Illustration of how a distributed antenna system (DAS) may be used inside a building.

4.4 Handoff

At the time of communication, if the strength of the signal diminishes, the communication is switched from one MSC to another MSC for high strength signal. This process is known as handoff. During a conversation, the mobile station may move from one cell to another. When it happens, the signal may become weak. To get the service and get the strong signal, the MSC switches control to another to give the service.

When a mobile user travels from one area of coverage or cell to another cell within a call's duration the call should be transferred to the new cell's base station. Otherwise, the call will be dropped because the link with the current base station becomes too weak as the mobile recedes. Indeed, this ability for transference is a design matter in mobile cellular system design and is call handoff.

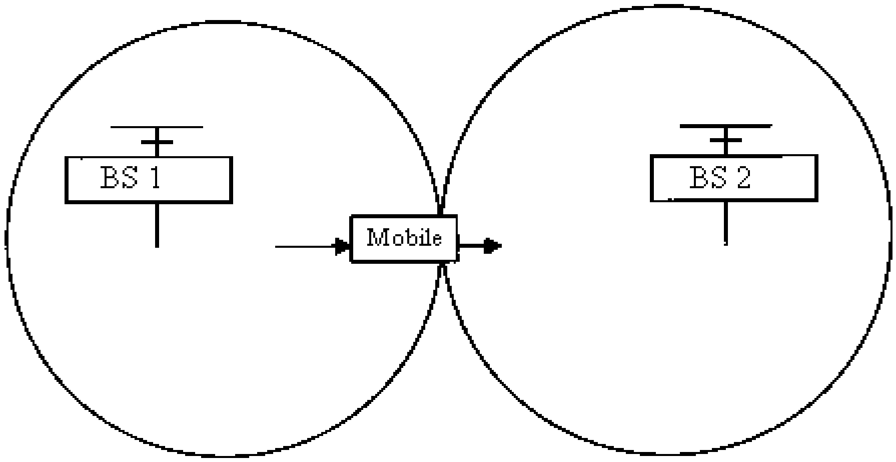


Figure 4.8: Illustration of Handoff

How handoff is initiated

- Each base station constantly monitors the signal strengths of all the voice channels.
- To measure the RSSI (Radio Signal Strength Indication) of the channels, a spare receiver called locator receiver is used.
- The locator receiver is controlled by MSC.
- Based on information of locator receiver, MSC decide whether handoff is necessary or not.

Controlling a handoff

- Cell site can assign a low handoff threshold to keep an MS in longer conversation or assign high threshold to request a handoff earlier.
- MSC can also control a handoff by making it earlier or later after receiving a handoff request from cell site.

4.4.1 Types of handoff

- Forced handoff
- Mobile assisted handoff
- Cell-site handoff
- Intersystem handoff
- Umbrella cell approach
- Soft handoff

4.4.1.1 Forced handoff

A handoff which would normally occur but prevented from happening, or a handoff that should not occur but is forced to happen.

4.4.1.2 Mobile assisted handoff

In mobile assisted handoff, every MS measures the received power from surrounding BS and continually reports the results of these measurements to the serving BS. A handoff is initiated when the power received from the neighboring base station begin to exceed the power received from the current base station by a certain level for a certain period of time. This type of handoff is called mobile assisted handoff.

4.4.1.3 Cell-site handoff

This scheme can be used in a non-cellular system. The mobile unit has been assigned a frequency and takes to its home cell site while it travels. When the mobile unit leaves its home cell and enters a new cell, its frequency does not change; rather the new cell must tune into the frequency of the mobile unit. In this case only the cell sites need the frequency information of the mobile unit. Then the aspects of mobile unit control can be greatly simplified, and there will be no need to provide handoff capability at the mobile unit.

4.4.1.4 Intersystem handoff

A call may be initiated in one cellular system (controlled by one MTSO) and enter another system (controlled by another MTSO) before terminating the call. For example, A car travels on a highway and the driver originates a call in system A. Then the car leaves cell site A of system A and enter cell site B of system B. Cell site A and B are controlled by two different MTSOs. When the mobile unit signal becomes weak in cell site A, MTSO A searches for a candidate cell site in its system and cannot find one. Then MTSOs A sends the handoff request to MTSO B through a dedicated line between MTSO A and MTSO B, and MTSO B makes a complete handoff during the cell conversation.

4.4.1.5 Umbrella cell approach

By using different antenna heights (often on the same building ore tower) and different power labels, it is possible to provide "large" and "small" cells which are co-located with some smaller micro cells at a large location. This technique is called the umbrella cell approach.

It is used to provide large area coverage to high speed users while providing small area coverage to user traveling low speed. Following figure illustrates an umbrella cell which is co-located with some smaller micro cells.

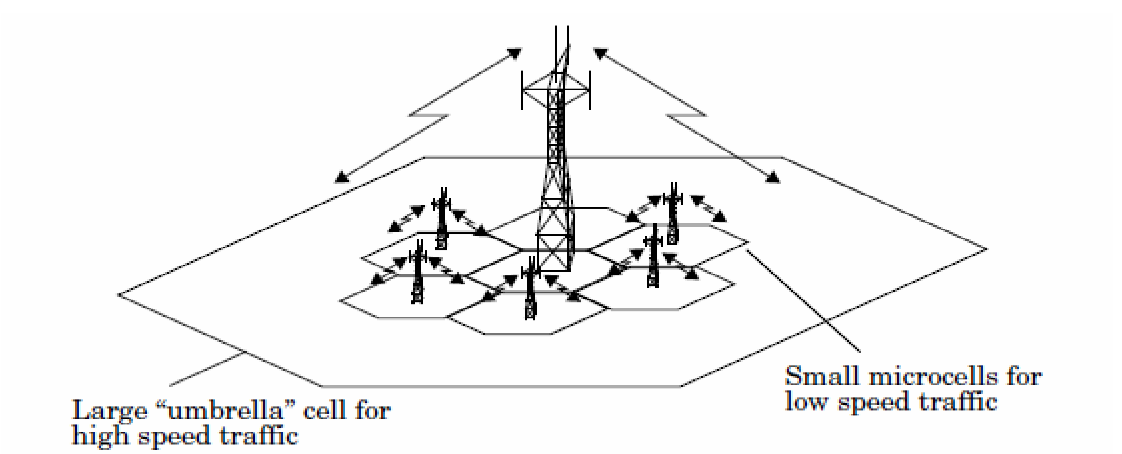


Figure 4.9: umbrella cell

4.4.1.6 Soft handoff

The ability to select between the instantaneous received signals from a variety of base station is called soft handoff. The Soft handoff is applied to CDMA. In CDMA system, all cells can use the same radio carrier. Therefore the frequency reuse factor is N=1. Since the operating radio carrier of all cells are the same, no need to change from one frequency to another frequency but change from one code to another code. Thus there is no hard handoff and this kind handoff is called soft handoff.

Chapter 5
Performance Criterion

5.1 Introduction

The principle purpose of the analysis for frequency reuse schemes is to improve the performance of the cellular communication system. There are lots of factors involved to the performance. Here important parameters behind the performance as described next section.

5.2 Performance criteria

Considered performance criterions are

1. Channel Capacity
2. Grade of Service (GoS)
3. Trunking Efficiency
4. Interference

5.2.1 Channel Capacity

Channel Capacity is measured by the available voice channels per cell, translated into Erlangs. It is also known as traffic or traffic intensity. Traffic is calculated by a number of ways

$$\text{Channel Capacity} = \frac{\text{number of available voice channel}}{\text{frequency reuse factor}} \qquad \text{.......}\ (5.1)$$

$$\text{Erlangs} = \frac{\text{number of calls} * \text{avarage call holding time}}{\text{3600 seconds}} \qquad \text{.......}\ (5.2)$$

Another way to calculate the traffic by means of Poisson's Distribution, which is a statistical process that applies to a sequence of events that take place at regular intervals of time or throughput or a continuous interval of time. The formula is given in next section.

5.2.2 Grade of Service (GoS)

Grade of Service (GoS) is defined as the probability of call failure. It means that a call will be lost due to transmission congestion i.e. when all the available channels are busy, any additional call will be denied access to the communication system. Let N be the total number of channel, T be the offered Traffic in erlangs, then the probability that all the channel being busy will be given by following Poisson's Distribution [1]

$$P(N;T) = \frac{T^N * e^{-T}}{N!} \qquad \text{…………….. (5.3)}$$

Where P(N;T) is the blocking rate or GoS. GoS lies between 0 and 1 (0<GoS<1). All calls will fail if GoS=1. This means that no service at all, zero revenue. All calls will pass if GoS=1. This is overprovision, poor revenue. Typically, GoS =0.02 (2%) in cellular communication system. The average value of GoS is .02 (2%) in mobile environment [3].

5.2.3 Trunking Efficiency

Trunking Efficiency (channel utilization efficiency) is also known as measure of base station efficiency. It is determined by amount of traffic per channel, defined as [1]

$$\text{Trunking efficiency } (\%) = \frac{\text{traffic in erlangs}}{\text{number of channels}} * 100 \qquad \text{………… (5.4)}$$

We see that for a given GoS, the efficiency increases as the number of trunks (voice channel) increases. A cell site having fewer than 15 voice channel is generally inefficient, less cost effective and generate poor revenue.

5.2.4 Interference

Interference is the major concern in cellular communication system. It is generally determined by the carrier-to-interference ratio (C/I), which in turn depends on frequency planning and antenna engineering. Adjacent channel interference (ACI) is also major concern if deployed in the adjacent site.

A co-channel interferer has the same nominal frequency as the desired frequency. It arises from multiple use of same frequency, which may be expressed in a number of ways.

- Co-channel interference (CCI) or interference to carrier ratio(I/C)
- Carrier to interference ratio (C/I)

Here difference between the CCI and C/I is CCI(dB) = - C/I(dB). The carrier to interference ratio (C/I) is defined by [1]

$$C/I = 10 \log [1/j*(D/R)^{\gamma}] \qquad \ldots\ldots\ldots\ldots\ldots (5.5)$$

Where,

j = number of co channel interferer

γ = propagation constant

D = frequency reuse distance

R = radius of the cell

The above equation may be written as

$$C/I = 10 \log [1/j*\{\sqrt{(3K)}\}^{\gamma}] \qquad \ldots\ldots\ldots\ldots\ldots (5.6)$$

Where,

D/R = √(3K) ; K= frequency reuse factor

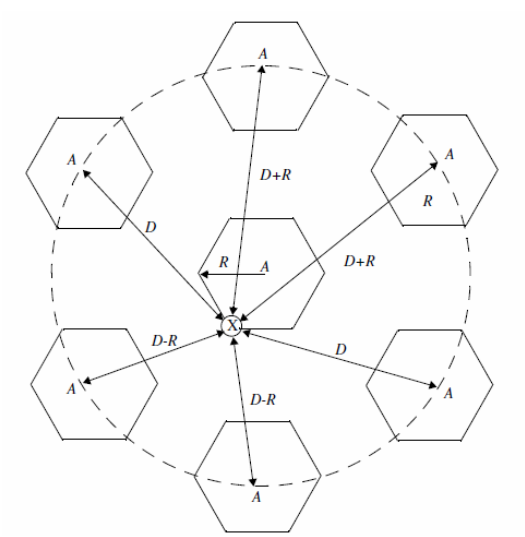


Figure5.1: Illustration of co-channel interference in 1st tier

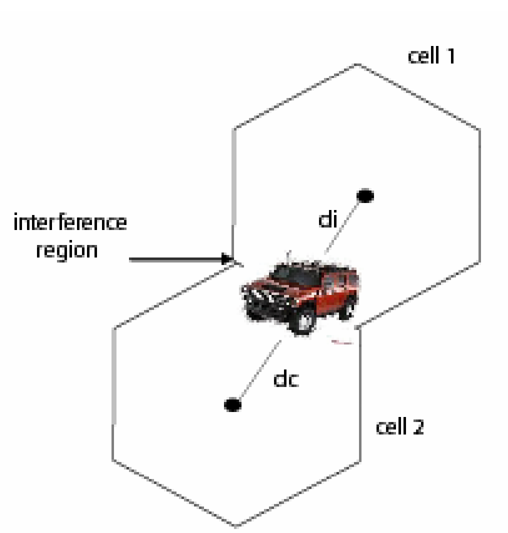


Figure 5.2: Adjacent channel interference

Adjacent channel interference arises from energy slipover between two adjacent channels. This can be evaluated with the aid of figure () where it is assumed that the adjacent channel is assigned to the adjacent site and the ratio d_i/d_c varies as the mobile moves toward away from the cell. Moreover, the ou of band signal are also assumed attenuated by the post modulation filter by at least 26 dB (EIA standard). Then the adjacent channel interference will be

$$ACI = -10 \log [(d_i/d_c)^{\gamma}] + \text{adjacent channel isolation} \qquad \text{.......... (5.7)}$$

Chapter 6
Simulation and Result

6.1 Introduction

The principle goal of the analysis done in various frequency reuse factor is for proper frequency planning. Here frequency planning means to optimize spectrum usage, enhance channel capacity, and reduce channel interference. Since FCC provides licenses to operate cellular communication system over a given band of frequencies. Because cellular communication is a multiple access system, operators have to comply with the regulation. Compliances requires proper frequency planning, spectrum control, and also involves channel numbering, channel grouping into subsets, cell planning and channel assignments. Also frequency planning is an important task in cellular communication for system planning, installations, and performance analysis etc. through our analysis we consider that the total performances are depends on channel capacity, grade of service, trunking efficiency, carrier to interference ratio, and adjacent channel interference.

6.2 Performance analysis

Based of the above performance criterion, we analysis the performance of various frequency reuse scheme for both OMNI and sectoring cell. It is to be noted that our all calculation for only GSM 1800, where total BW = 75 MHz, channel BW = 200 KHz, and total number of channel = 375.

6.2.1. Algorithm for OMNI

Algorithm Omni

Begin

Set number of co channel interferer (j) = 6;
Set grade of service = 0.02;
Set frequency reuse factor (frf) = [1 3 4 7 9 12];

Set total channel (tch) = [375 375 375 375 375 375];
Set number of channel per cel (cec) = ceil(tch./frf);

//Initialization

Traffic for 1% gos (tr1) = [350.75 107.75 78.4 41.5 30.8 22];
Traffic for 2% gos (tr2) = [360.8 112.3 82.2 44 32.8 23.7];
Traffic for 3% gos (tr3) = [368.4 115.6 84.9 45.8 34.3 24.9];

//Processing

Trunking efficiency for 1% = (tr1./cec).*100;
Trunking efficiency for 2% = (tr2./cec).*100;
Trunking efficiency for 3% = (tr3./cec).*100;

//Output

Co-channel interference =10*(log10((1/j)*(3*frf).^2));

End

6.2.2 Algorithm for Sectoring cell

Algorithm sectoring

Begin

Set number of co channel interferer (js)= 2;
Set grade of service (gos) = 0.02;
Set frequency reuse factor (frf) =[1 3 4 7];
Set total channel (tch)=[375 375 375 375];
Set number of channel per cel (cec) = ceil(tch./frf);
Set number of channel per sector with 3 sector (cps3) = ceil(cec/3);
Set number of channel per sector with 4 sector (cps4) = ceil(cec/4);
Set number of channel per sector with 6 sector (cps6) = ceil(cec/6);

// Initialization

Traffic with 1% gos for 3 sector (trs13) = [107.75 30.8 22 10.4];
Traffic with 2% gos for 3 sector (trs23) = [112.3 32.8 23.7 11.5];
Traffic with 3% gos for 3 sector (trs33) = [115.6 34.3 24.9 12.2];
Traffic with 1% gos for 4 sector (trs14) = [78.4 22 15.3 7.35];
Traffic with 2% gos for 4 sector (trs24) = [82.2 23.7 16.6 8.20];
Traffic with 3% gos for 4 sector (trs34) = [84.9 24.9 17.6 8.80];
Traffic with 1% gos for 6 sector (trs16) = [49.7 12 8.88 3.78];

Traffic with 2% gos for 6 sector (trs26) = [52.5 13.2 9.83 4.34];
Traffic with 3% gos for 6 sector (trs36) = [54.5 14 10.5 4.75];

//Processing

Trunking efficiency with 1% gos for 3 sector = (trs13./cps3).*100;
Trunking efficiency with 2% gos for 3 sector = (trs23./cps3).*100;
Trunking efficiency with 3% gos for 3 sector = (trs33./cps3).*100;
Trunking efficiency with 1% gos for 4 sector = (trs14./cps4).*100;
Trunking efficiency with 2% gos for 4 sector = (trs24./cps4).*100;
Trunking efficiency with 3% gos for 4 sector = (trs34./cps4).*100;
Trunking efficiency with 1% gos for 6 sector = (trs16./cps6).*100;
Trunking efficiency with 2% gos for 6 sector = (trs26./cps6).*100;
Trunking efficiency with 3% gos for 6 sector = (trs36./cps6).*100;

// Output

Co-channel interference for sectoring = 10*(log10((1/js)*(3*frf).^2));

End

6.2.3 Analysis for OMNI cell

The cell uses omni directional antenna is known as omni cell. An omni directional antenna is an antenna system which radiates power uniformly in one plane with a directive pattern shape in a perpendicular plane. This pattern is often described as "donut shaped". Omni directional antenna can be used to link multiple directional antennas in outdoor point to multipoint communication systems including cellular phone connections and TV broadcasts [1]. Omni directional antennas, the most popular type being the dipole antenna, are antennas with a 360-degree horizontal propagation pattern. In other words, they propagate most of their energy outward in a 360-degree pattern shaped much like a doughnut—though a very thick one. Performance calculation for frequency reuse factor 7 is shown below with considering GSM 1800 system, where total BW 75 MHz, channel BW 200 KHz.

- Number of voice channel per cell = 375/7 ≈ 54
- Traffic, T = 44 erlang , with 2% GoS for 54 channels

- Trunking Efficiency = (44/54)*100 = 81.48%
- C/I = $10*\log[(1/6)* \sqrt{(3*7)^4}]$ = 18.66 dB

Table 6.1: Performance evolution of frequency reuse factors for omni cell

FRF	No. of voice channel/cell	Traffic (1% GoS) Erlang	Traffic (2% GoS) Erlang	Traffic (3% GoS) Erlang	Trunking efficiency (2% GoS)	C/I (dB)
1	375	350.75	360.8	368.4	96.2%	1.78
3	125	107.75	112.3	115.6	89.8%	11.3
4	94	78.4	82.2	84.9	87.5%	13.8
7	54	41.5	44	45.8	81.5%	18.7
9	42	30.8	32.8	34.3	78%	20.9
12	32	22	23.7	24.9	74%	23.3

6.2.4 Analysis for sectoring cell

Sectorization scheme is achieved by dividing a cell into number of sectors. It may 3sectors (120 degree), 4 sectors (90 degree), 6 sectors (60 degree) etc. each sector is treated as a logical omni cell, where directional antenna are used in each sector. Here the directional antenna may be semi directional or highly directional. Semi directional antennas are antennas that focus most of their energy in a particular direction. Examples include patch, panel, and Yagi antennas. Highly directional antennas are antennas that transmit with a very narrow beam. These types of antennas often look like the satellite dish. They are generally called parabolic dish or grid antennas. Due to the high directionality of these antennas, they are mostly used for PtP or PtMP links [4]. A sectorized antenna (or sector antenna) is a high-gain antenna that works back-to-back with other sectorized antennas. They are often mounted around a pole or mast and can provide coverage in indoor environments, such as warehouses, or outdoor environments, such as university campuses or hotspots.

Table 6.2: Performance evolution of frequency reuse factors for Sectoring cell

FRF	No. of sectors	No. of channel	Traffic (1%GoS) Erlang	Traffic (2%GoS) Erlang	Traffic (3%GoS) Erlang	Trunking efficiency (1%GoS)	Trunking efficiency (2%GoS)	Trunking efficiency (3%GoS)	C/I (dB)
1	3	125	107.75	112.3	115.6	86%	89%	92%	6.53
	4	94	78.4	82.2	84.9	83%	87%	90%	
	6	63	49.7	52.5	54.5	79%	83%	87%	
3	3	42	30.8	32.8	34.3	73%	78%	82%	16
	4	32	22	23.7	24.9	69%	74%	78%	
	6	20	12	13.2	14	60%	66%	70%	
4	3	32	22	23.7	24.9	69%	75%	78%	18.7
	4	24	15.3	16.6	17.6	64%	69%	73%	
	6	16	8.88	9.83	10.5	56%	61%	66%	
7	3	18	10.8	11.5	12.2	58%	64%	68%	23.4
	4	14	7.35	8.20	8.80	53%	59%	63%	
	6	9	3.78	4.34	4.75	42%	48%	53%	

6.2.5 Graphical representation of performance

Using MATLAB R2008a, we calculated the performance of frequency reuse factors for both OMNI and sectoring cell. Since, the numbers of available channels are limited therefore as a RF engineer the frequency needs to be reused properly to get the desired demand.

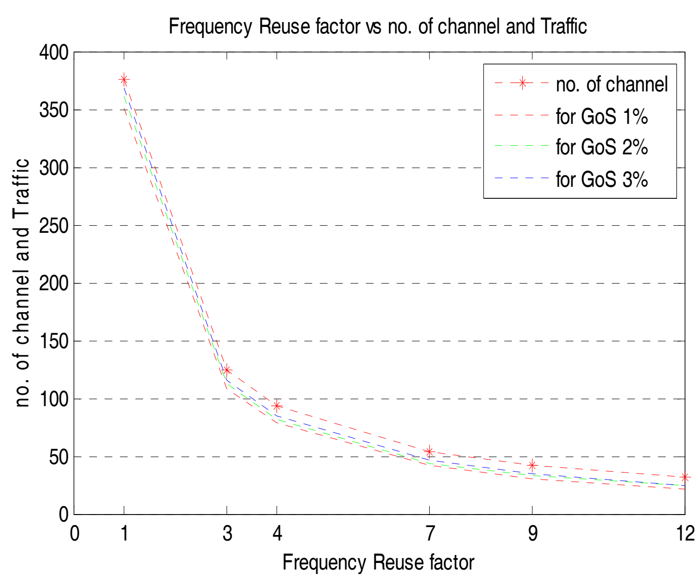


Figure 6.1: Relation between Frequency Reuse Factor, Traffic and no of channel for omni cell

We see that, Traffic depends on number of channels and Trunking efficiency depends on Traffic and finally number of channel depends on frequency reuse factors (FRF). It is obvious that with the increase of FRF number of channel decreases. Therefore Traffic also decreases as shown in figure 6.1, 6.2 and 6.3

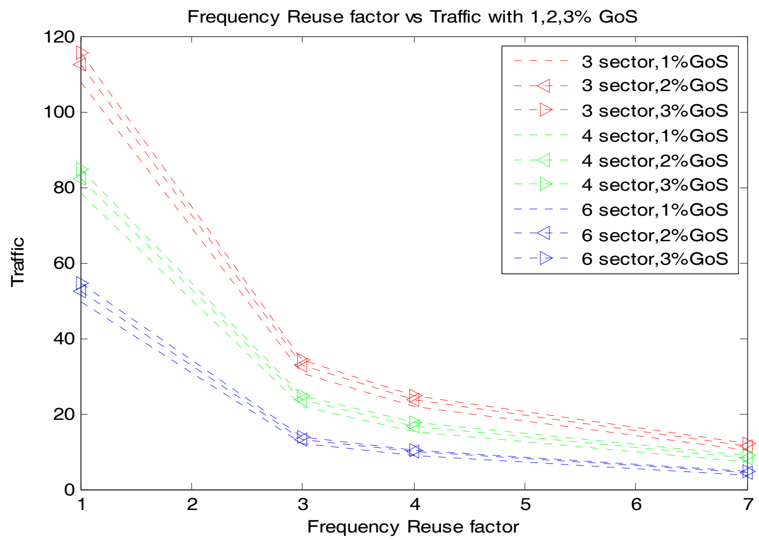


Figure 6.2: Relation between Frequency Reuse Factor and Traffic for sectoring cell

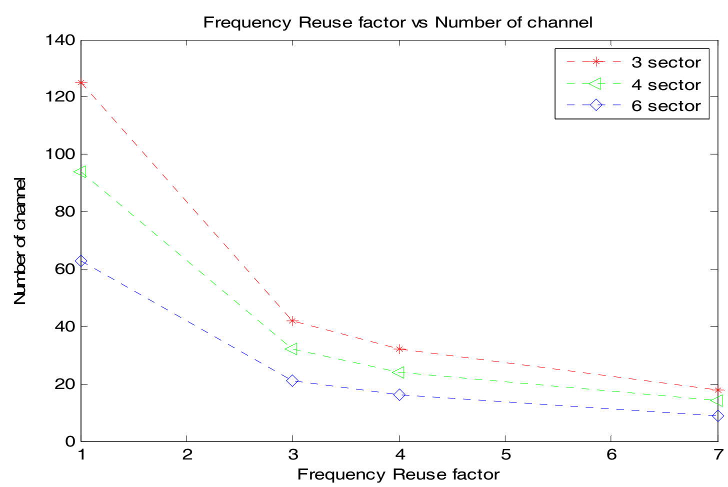


Figure 6.3: Relation between Frequency Reuse Factor and no of channel for Sectoring cell

Since Trunking efficiency depends on Traffic in erlang. We see that, with the increase in FRF Trunking efficiency decreases. It is to be noted that Traffic not only depends on number of channel but also depends on Grade of Service (GoS). Figure 5.4 shows the relationship between FRF and Trunking efficiency for both OMNI and sectoring cell. Note that in mobile environment 2% GoS are considered.

For OMNI Cell

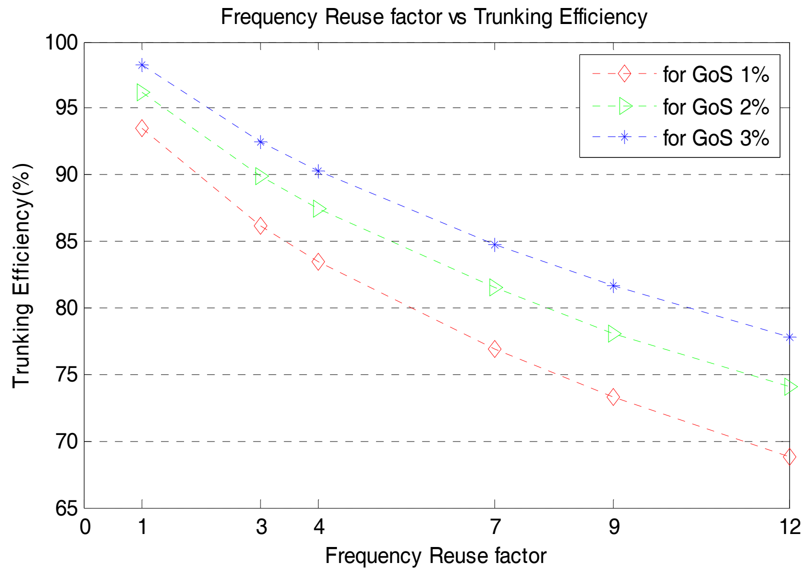


Figure 6.4(a)

For Sectoring Cell

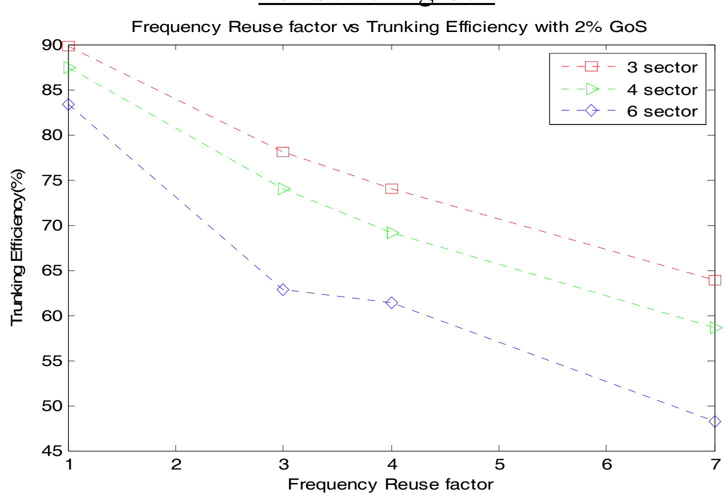


Figure 6.4 (b)

Figure 6.4: Relation between Frequency Reuse Factor and Trunking Efficiency

Figure 6.5 shows the relation with FRF for both OMNI and Sectoring cell from where one can easily take the decision about which FRF perform better in OMNI and Sectoring cell concept.

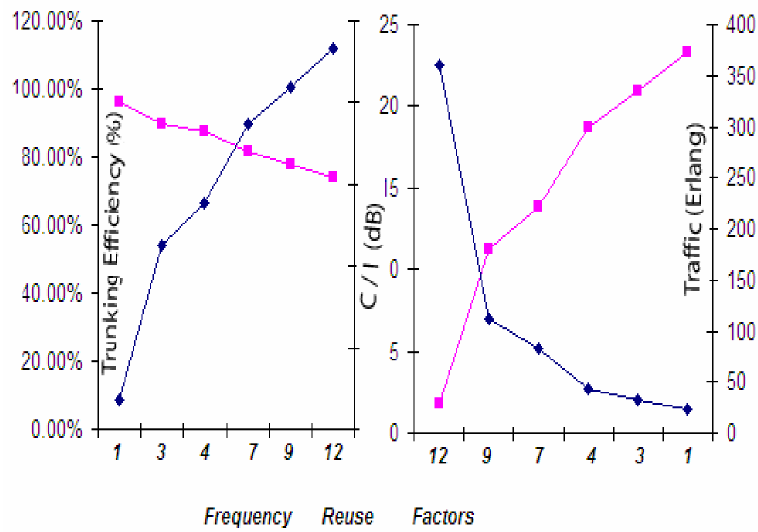


Figure 6.5 (a): Relation between FRF and Trunking Efficiency, Traffic, and C/I for OMNI Cell

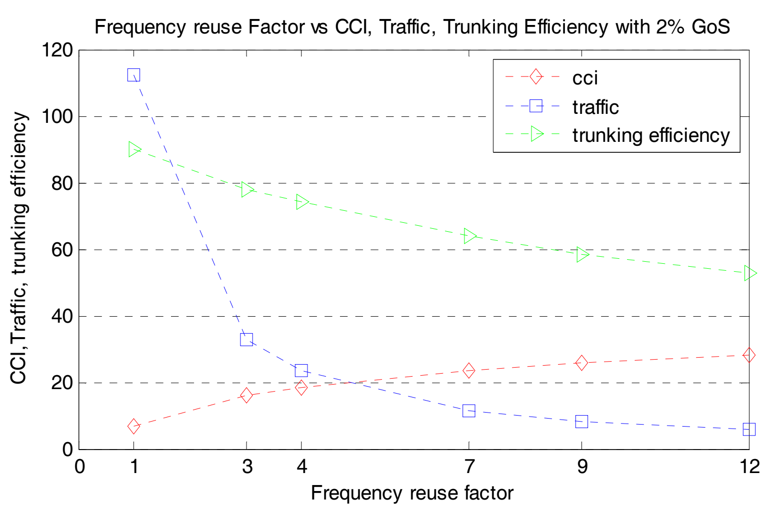


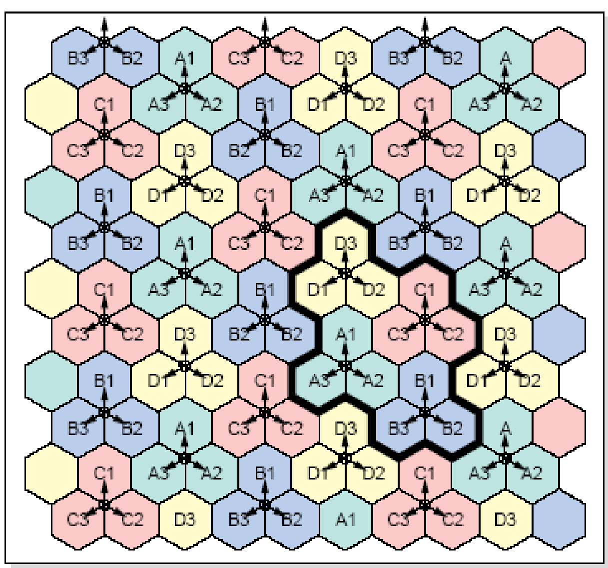
Figure 6.5(b): Relation between FRF and Trunking Efficiency, Traffic, and C/I for Sectoring cell

6.3 Frequency Planning

Since Frequency planning is an important task in cellular communications for system planning, installation, performance analysis, capacity analysis etc. from our analysis we give three frequency plan for three propagation environment i.e. Urban, Rural, and highways or coastal areas.

6.3.1 Frequency Plan for Urban Areas

Frequency planning is the most important concern for radio engineers especially in urban environment. Because in this environment the RF signal faced lots of impairements. The most important factor is multipath propagation due to buildings. The received signals in this environment are a result of direct rays, reflected rays, and shadowing or any combination of these signal components. Therefore interference is great issue in this environment. Another important issue is about its population density. The urban environment is highly populated i.e. high traffic density. Therefore more voice channel must be ensuring to provide Quality of Service (QoS).



4/12 Cell Pattern

Figure 6.6: FRF 4 with 120 degree sectorization

Considering all above factors and evaluated performance, we proposed FRF 4, 120 degree sectorization (3 sectors). Now may question me why you not choose OMNI cell due to FRF for omni provide greater number of channel, traffic, and also trunking efficiency as well. Ok I asked this question by giving the reference of Electronic Industry Association (EIA) standard about C/I. The standard defines that C/I ≈ 17 dB [1]. But FRF 4 OMNI give C/I =13.8dB.

6.3.2 Frequency Plan for Rural Areas

This is the area where the population is low. High gain antenna with wide opening angle is possible in this kind of coverage. Since, in this environment population density (Traffic) is very low. Hence, capacity and traffic is not a great issue here. But simply we say about coverage. Also multipath propagation is not a factor in this environment. Therefore we proposed FRF 7 OMNI cell concept.

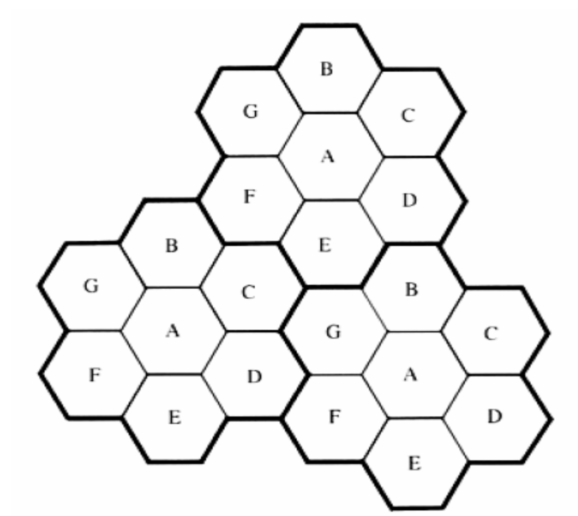


Figure 6.10: Frequency Reuse Factor 7

6.3.3 Frequency Plan for Highways or Coastal Areas

Sectoring the cell increase the Handoff due to a cell is divided by the number of sectors. As a result the cell size is reduced and handoff occurs. So OMNI cell concept must be applied in this environment to decrease the handoff. We therefore proposed FRF 7 OMNI Trapezoidal plan, which is quite difference as proposed in section 5.5.2. A Trapezoidal plan is based on arranging a cluster of seven cells in two rows that have alternating channel assignments. This is shown in figure 5.9, where the adjacent channels are completely eliminated. Because of the appearance of the cluster, this configuration is termed as a Trapezoidal configuration. The growth plan is shown in figure 5.9. only horizontal expansion is possible in this plan; for this reason it is suitable for highways and coastal areas.

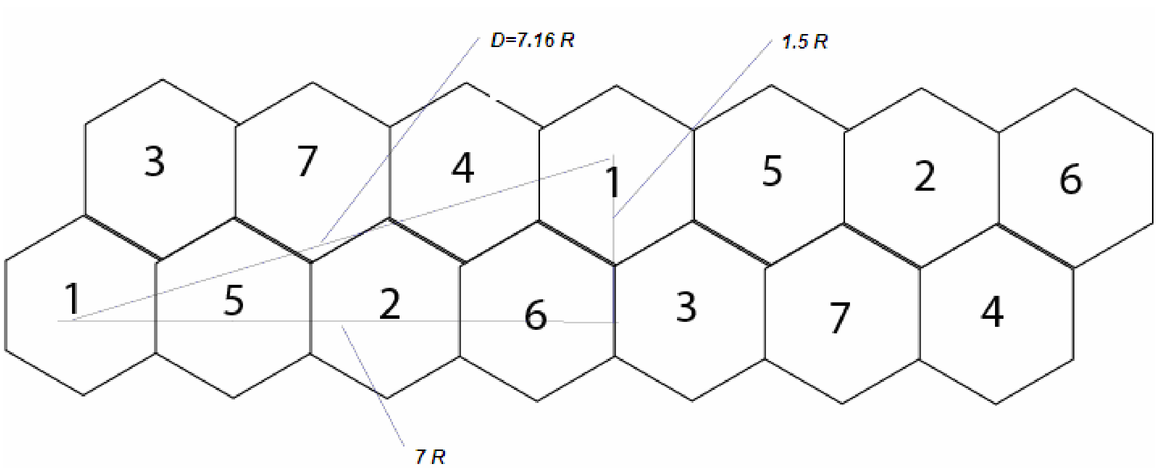


Figure 6.11: Trapezoidal Growth Plan

Here the reuse distance may be obtained by means of plane geometry. This is given by D/R = 7.6

CHAPTER 7
CONCLUSION

In this thesis, the performance of frequency reuse schemes in mobile cellular environment has been simulated and evaluated. Based on simulation, two respective models (sectoring and omni cells) for two propagation environment (urban and rural areas) have been proposed. The demand of the traffic and all factors related with performance respective model for different environment has also been proposed. Finally it is experimented in different geographical areas, especially in rural and urban areas and then it has been found the satisfactory level of traffic.

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Erlang B Traffic Table

Maximum Offered Load Versus B and N

B is in %

N/B	0.01	0.05	0.1	0.5	1.0	2	5	10	15	20	30	40
1	.0001	.0005	.0010	.0050	.0101	.0204	.0526	.1111	.1765	.2500	.4286	.6667
2	.0142	.0321	.0458	.1054	.1526	.2235	.3813	.5954	.7962	1.000	1.449	2.000
3	.0868	.1517	.1938	.3490	.4555	.6022	.8994	1.271	1.603	1.930	2.633	3.480
4	.2347	.3624	.4393	.7012	.8694	1.092	1.525	2.045	2.501	2.945	3.891	5.021
5	.4520	.6486	.7621	1.132	1.361	1.657	2.219	2.881	3.454	4.010	5.189	6.596
6	.7282	.9957	1.146	1.622	1.909	2.276	2.960	3.758	4.445	5.109	6.514	8.191
7	1.054	1.392	1.579	2.158	2.501	2.935	3.738	4.666	5.461	6.230	7.856	9.800
8	1.422	1.830	2.051	2.730	3.128	3.627	4.543	5.597	6.498	7.369	9.213	11.42
9	1.826	2.302	2.558	3.333	3.783	4.345	5.370	6.546	7.551	8.522	10.58	13.05
10	2.260	2.803	3.092	3.961	4.461	5.084	6.216	7.511	8.616	9.685	11.95	14.68
11	2.722	3.329	3.651	4.610	5.160	5.842	7.076	8.487	9.691	10.86	13.33	16.31
12	3.207	3.878	4.231	5.279	5.876	6.615	7.950	9.474	10.78	12.04	14.72	17.95
13	3.713	4.447	4.831	5.964	6.607	7.402	8.835	10.47	11.87	13.22	16.11	19.60
14	4.239	5.032	5.446	6.663	7.352	8.200	9.730	11.47	12.97	14.41	17.50	21.24
15	4.781	5.634	6.077	7.376	8.108	9.010	10.63	12.48	14.07	15.61	18.90	22.89
16	5.339	6.250	6.722	8.100	8.875	9.828	11.54	13.50	15.18	16.81	20.30	24.54
17	5.911	6.878	7.378	8.834	9.652	10.66	12.46	14.52	16.29	18.01	21.70	26.19
18	6.496	7.519	8.046	9.578	10.44	11.49	13.39	15.55	17.41	19.22	23.10	27.84
19	7.093	8.170	8.724	10.33	11.23	12.33	14.32	16.58	18.53	20.42	24.51	29.50
20	7.701	8.831	9.412	11.09	12.03	13.18	15.25	17.61	19.65	21.64	25.92	31.15
21	8.319	9.501	10.11	11.86	12.84	14.04	16.19	18.65	20.77	22.85	27.33	32.81
22	8.946	10.18	10.81	12.64	13.65	14.90	17.13	19.69	21.90	24.06	28.74	34.46
23	9.583	10.87	11.52	13.42	14.47	15.76	18.08	20.74	23.03	25.28	30.15	36.12
24	10.23	11.56	12.24	14.20	15.30	16.63	19.03	21.78	24.16	26.50	31.56	37.78
25	10.88	12.26	12.97	15.00	16.13	17.51	19.99	22.83	25.30	27.72	32.97	39.44
26	11.54	12.97	13.70	15.80	16.96	18.38	20.94	23.89	26.43	28.94	34.39	41.10
27	12.21	13.69	14.44	16.60	17.80	19.27	21.90	24.94	27.57	30.16	35.80	42.76
28	12.88	14.41	15.18	17.41	18.64	20.15	22.87	26.00	28.71	31.39	37.21	44.41
29	13.56	15.13	15.93	18.22	19.49	21.04	23.83	27.05	29.85	32.61	38.63	46.07
30	14.25	15.86	16.68	19.03	20.34	21.93	24.80	28.11	31.00	33.84	40.05	47.74
31	14.94	16.60	17.44	19.85	21.19	22.83	25.77	29.17	32.14	35.07	41.46	49.40
32	15.63	17.34	18.21	20.68	22.05	23.73	26.75	30.24	33.28	36.30	42.88	51.06
33	16.34	18.09	18.97	21.51	22.91	24.63	27.72	31.30	34.43	37.52	44.30	52.72
34	17.04	18.84	19.74	22.34	23.77	25.53	28.70	32.37	35.58	38.75	45.72	54.38
35	17.75	19.59	20.52	23.17	24.64	26.44	29.68	33.43	36.72	39.99	47.14	56.04
36	18.47	20.35	21.30	24.01	25.51	27.34	30.66	34.50	37.87	41.22	48.56	57.70
37	19.19	21.11	22.08	24.85	26.38	28.25	31.64	35.57	39.02	42.45	49.98	59.37
38	19.91	21.87	22.86	25.69	27.25	29.17	32.62	36.64	40.17	43.68	51.40	61.03
39	20.64	22.64	23.65	26.53	28.13	30.08	33.61	37.72	41.32	44.91	52.82	62.69
40	21.37	23.41	24.44	27.38	29.01	31.00	34.60	38.79	42.48	46.15	54.24	64.35
41	22.11	24.19	25.24	28.23	29.89	31.92	35.58	39.86	43.63	47.38	55.66	66.02
42	22.85	24.97	26.04	29.09	30.77	32.84	36.57	40.94	44.78	48.62	57.08	67.68
43	23.59	25.75	26.84	29.94	31.66	33.76	37.57	42.01	45.94	49.85	58.50	69.34

44	24.33	26.53	27.64	30.80	32.54	34.68	38.56	43.09	47.09	51.09	59.92	71.01
45	25.08	27.32	28.45	31.66	33.43	35.61	39.55	44.17	48.25	52.32	61.35	72.67
46	25.83	28.11	29.26	32.52	34.32	36.53	40.55	45.24	49.40	53.56	62.77	74.33
47	26.59	28.90	30.07	33.38	35.22	37.46	41.54	46.32	50.56	54.80	64.19	76.00
48	27.34	29.70	30.88	34.25	36.11	38.39	42.54	47.40	51.71	56.03	65.61	77.66
49	28.10	30.49	31.69	35.11	37.00	39.32	43.53	48.48	52.87	57.27	67.04	79.32
50	28.87	31.29	32.51	35.98	37.90	40.26	44.53	49.56	54.03	58.51	68.46	80.99
51	29.63	32.09	33.33	36.85	38.80	41.19	45.53	50.64	55.19	59.75	69.88	82.65
52	30.40	32.90	34.15	37.72	39.70	42.12	46.53	51.73	56.35	60.99	71.31	84.32
53	31.17	33.70	34.98	38.60	40.60	43.06	47.53	52.81	57.50	62.22	72.73	85.98
54	31.94	34.51	35.80	39.47	41.51	44.00	48.54	53.89	58.66	63.46	74.15	87.65
55	32.72	35.32	36.63	40.35	42.41	44.94	49.54	54.98	59.82	64.70	75.58	89.31
56	33.49	36.13	37.46	41.23	43.32	45.88	50.54	56.06	60.98	65.94	77.00	90.97
57	34.27	36.95	38.29	42.11	44.22	46.82	51.55	57.14	62.14	67.18	78.43	92.64
58	35.05	37.76	39.12	42.99	45.13	47.76	52.55	58.23	63.31	68.42	79.85	94.30
59	35.84	38.58	39.96	43.87	46.04	48.70	53.56	59.32	64.47	69.66	81.27	95.97
60	36.62	39.40	40.80	44.76	46.95	49.64	54.57	60.40	65.63	70.90	82.70	97.63
61	37.41	40.22	41.63	45.64	47.86	50.59	55.57	61.49	66.79	72.14	84.12	99.30
62	38.20	41.05	42.47	46.53	48.77	51.53	56.58	62.58	67.95	73.38	85.55	101.0
63	38.99	41.87	43.31	47.42	49.69	52.48	57.59	63.66	69.11	74.63	86.97	102.6
64	39.78	42.70	44.16	48.31	50.60	53.43	58.60	64.75	70.28	75.87	88.40	104.3
65	40.58	43.52	45.00	49.20	51.52	54.38	59.61	65.84	71.44	77.11	89.82	106.0
66	41.38	44.35	45.85	50.09	52.44	55.33	60.62	66.93	72.60	78.35	91.25	107.6
67	42.17	45.18	46.69	50.98	53.35	56.28	61.63	68.02	73.77	79.59	92.67	109.3
68	42.97	46.02	47.54	51.87	54.27	57.23	62.64	69.11	74.93	80.83	94.10	111.0
69	43.77	46.85	48.39	52.77	55.19	58.18	63.65	70.20	76.09	82.08	95.52	112.6
70	44.58	47.68	49.24	53.66	56.11	59.13	64.67	71.29	77.26	83.32	96.95	114.3
71	45.38	48.52	50.09	54.56	57.03	60.08	65.68	72.38	78.42	84.56	98.37	116.0
72	46.19	49.36	50.94	55.46	57.96	61.04	66.69	73.47	79.59	85.80	99.80	117.6
73	47.00	50.20	51.80	56.35	58.88	61.99	67.71	74.56	80.75	87.05	101.2	119.3
74	47.81	51.04	52.65	57.25	59.80	62.95	68.72	75.65	81.92	88.29	102.7	120.9
75	48.62	51.88	53.51	58.15	60.73	63.90	69.74	76.74	83.08	89.53	104.1	122.6
76	49.43	52.72	54.37	59.05	61.65	64.86	70.75	77.83	84.25	90.78	105.5	124.3
77	50.24	53.56	55.23	59.96	62.58	65.81	71.77	78.93	85.41	92.02	106.9	125.9
78	51.05	54.41	56.09	60.86	63.51	66.77	72.79	80.02	86.58	93.26	108.4	127.6
79	51.87	55.25	56.95	61.76	64.43	67.73	73.80	81.11	87.74	94.51	109.8	129.3
80	52.69	56.10	57.81	62.67	65.36	68.69	74.82	82.20	88.91	95.75	111.2	130.9
81	53.51	56.95	58.67	63.57	66.29	69.65	75.84	83.30	90.08	96.99	112.6	132.6
82	54.33	57.80	59.54	64.48	67.22	70.61	76.86	84.39	91.24	98.24	114.1	134.3
83	55.15	58.65	60.40	65.39	68.15	71.57	77.87	85.48	92.41	99.48	115.5	135.9
84	55.97	59.50	61.27	66.29	69.08	72.53	78.89	86.58	93.58	100.7	116.9	137.6
85	56.79	60.35	62.14	67.20	70.02	73.49	79.91	87.67	94.74	102.0	118.3	139.3
86	57.62	61.21	63.00	68.11	70.95	74.45	80.93	88.77	95.91	103.2	119.8	140.9
87	58.44	62.06	63.87	69.02	71.88	75.42	81.95	89.86	97.08	104.5	121.2	142.6
88	59.27	62.92	64.74	69.93	72.82	76.38	82.97	90.96	98.25	105.7	122.6	144.3
89	60.10	63.77	65.61	70.84	73.75	77.34	83.99	92.05	99.41	107.0	124.0	145.9
90	60.92	64.63	66.48	71.76	74.68	78.31	85.01	93.15	100.6	108.2	125.5	147.6

91	61.75	65.49	67.36	72.67	75.62	79.27	86.04	94.24	101.8	109.4	126.9	149.3
92	62.58	66.35	68.23	73.58	76.56	80.24	87.06	95.34	102.9	110.7	128.3	150.9
93	63.42	67.21	69.10	74.50	77.49	81.20	88.08	96.43	104.1	111.9	129.8	152.6
94	64.25	68.07	69.98	75.41	78.43	82.17	89.10	97.53	105.3	113.2	131.2	154.3
95	65.08	68.93	70.85	76.33	79.37	83.13	90.12	98.63	106.4	114.4	132.6	155.9
96	65.92	69.79	71.73	77.24	80.31	84.10	91.15	99.72	107.6	115.7	134.0	157.6
97	66.75	70.65	72.61	78.16	81.25	85.07	92.17	100.8	108.8	116.9	135.5	159.3
98	67.59	71.52	73.48	79.07	82.18	86.04	93.19	101.9	109.9	118.2	136.9	160.9
99	68.43	72.38	74.36	79.99	83.12	87.00	94.22	103.0	111.1	119.4	138.3	162.6
100	69.27	7~.25	75.24	80.91	84.06	87.97	95.24	104.1	112.3	120.6	139.7	164.3

N is the number of servers. The numerical column headings indicate blocking probability B in %. Table generated by Dan Dexter

Erlang C Traffic Table

Maximum Offered Load Versus B and N
B is in %

N/B	0.01	0.05	0.1	0.5	1.0	2	5	10	15	20	30	40
1	.0001	.0005	.0010	.0050	.0100	.0200	.0500	.1000	.1500	.2000	.3000	.4000
2	.0142	.0319	.0452	.1025	.1465	.2103	.3422	.5000	.6278	.7403	.9390	1.117
3	.0860	.1490	.1894	.3339	.4291	.5545	.7876	1.040	1.231	1.393	1.667	1.903
4	.2310	.3533	.4257	.6641	.8100	.9939	1.319	1.653	1.899	2.102	2.440	2.725
5	.4428	.6289	.7342	1.065	1.259	1.497	1.905	2.313	2.607	2.847	3.241	3.569
6	.7110	.9616	1.099	1.519	1.758	2.047	2.532	3.007	3.344	3.617	4.062	4.428
7	1.026	1.341	1.510	2.014	2.297	2.633	3.188	3.725	4.103	4.406	4.897	5.298
8	1.382	1.758	1.958	2.543	2.866	3.246	3.869	4.463	4.878	5.210	5.744	6.178
9	1.771	2.208	2.436	3.100	3.460	3.883	4.569	5.218	5.668	6.027	6.600	7.065
10	2.189	2.685	2.942	3.679	4.077	4.540	5.285	5.986	6.469	6.853	7.465	7.959
11	2.634	3.186	3.470	4.279	4.712	5.213	6.015	6.765	7.280	7.688	8.336	8.857
12	3.100	3.708	4.018	4.896	5.363	5.901	6.758	7.554	8.099	8.530	9.212	9.761
13	3.587	4.248	4.584	5.529	6.028	6.602	7.511	8.352	8.926	9.379	10.09	10.67
14	4.092	4.805	5.166	6.175	6.705	7.313	8.273	9.158	9.760	10.23	10.98	11.58
15	4.614	5.377	5.762	6.833	7.394	8.035	9.044	9.970	10.60	11.09	11.87	12.49
16	5.150	5.962	6.371	7.502	8.093	8.766	9.822	10.79	11.44	11.96	12.77	13.41
17	5.699	6.560	6.991	8.182	8.801	9.505	10.61	11.61	12.29	12.83	13.66	14.33
18	6.261	7.169	7.622	8.871	9.518	10.25	11.40	12.44	13.15	13.70	14.56	15.25
19	6.835	7.788	8.263	9.568	10.24	11.01	12.20	13.28	14.01	14.58	15.47	16.18
20	7.419	8.417	8.914	10.27	10.97	11.77	13.00	14.12	14.87	15.45	16.37	17.10
21	8.013	9.055	9.572	10.99	11.71	12.53	13.81	14.96	15.73	16.34	17.28	18.03
22	8.616	9.702	10.24	11.70	12.46	13.30	14.62	15.81	16.60	17.22	18.19	18.96
23	9.228	10.36	10.91	12.43	13.21	14.08	15.43	16.65	17.47	18.11	19.10	19.89
24	9.848	11.02	11.59	13.16	13.96	14.86	16.25	17.51	18.35	19.00	20.02	20.82
25	10.48	11.69	12.28	13.90	14.72	15.65	17.08	18.36	19.22	19.89	20.93	21.76
26	11.11	12.36	12.97	14.64	15.49	16.44	17.91	19.22	20.10	20.79	21.85	22.69
27	11.75	13.04	13.67	15.38	16.26	17.23	18.74	20.08	20.98	21.68	22.77	23.63
28	12.40	13.73	14.38	16.14	17.03	18.03	19.57	20.95	21.87	22.58	23.69	24.57
29	13.05	14.42	15.09	16.89	17.81	18.83	20.41	21.82	22.75	23.48	24.61	25.50
30	13.71	15.12	15.80	17.65	18.59	19.64	21.25	22.68	23.64	24.38	25.54	26.44
31	14.38	15.82	16.52	18.42	19.37	20.45	22.09	23.56	24.53	25.29	26.46	27.38
32	15.05	16.53	17.25	19.18	20.16	21.26	22.93	24.43	25.42	26.19	27.39	28.33
33	15.72	17.24	17.97	19.95	20.95	22.07	23.78	25.30	26.32	27.10	28.31	29.27
34	16.40	17.95	18.71	20.73	21.75	22.89	24.63	26.18	27.21	28.01	29.24	30.21
35	17.09	18.67	19.44	21.51	22.55	23.71	25.48	27.06	28.11	28.92	30.17	31.16
36	17.78	19.39	20.18	22.29	23.35	24.53	26.34	27.94	29.00	29.83	31.10	32.10
37	18.47	20.12	20.92	23.07	24.15	25.36	27.19	28.82	29.90	30.74	32.03	33.05
38	19.17	20.85	21.67	23.86	24.96	26.18	28.05	29.71	30.80	31.65	32.97	34.00
39	19.87	21.59	22.42	24.65	25.77	27.01	28.91	30.59	31.71	32.57	33.90	34.94
40	20.58	22.33	23.17	25.44	26.58	27.84	29.77	31.48	32.61	33.48	34.83	35.89
41	21.28	23.07	23.93	26.23	27.39	28.68	30.63	32.37	33.51	34.40	35.77	36.84
42	22.00	23.81	24.69	27.03	28.21	29.51	31.50	33.26	34.42	35.32	36.70	37.79
43	22.71	24.56	25.45	27.83	29.02	30.35	32.36	34.15	35.33	36.23	37.64	38.74

44	23.43	25.31	26.22	28.63	29.84	31.19	33.23	35.04	36.23	37.15	38.58	39.69
45	24.15	26.06	26.98	29.44	30.67	32.03	34.10	35.93	37.14	38.07	39.51	40.64
46	24.88	26.82	27.75	30.24	31.49	32.87	34.97	36.83	38.05	39.00	40.45	41.59
47	25.60	27.57	28.52	31.05	32.32	33.72	35.84	37.72	38.96	39.92	41.39	42.54
48	26.34	28.33	29.30	31.86	33.14	34.56	36.72	38.62	39.87	40.84	42.33	43.50
49	27.07	29.10	30.08	32.68	33.97	35.41	37.59	39.52	40.79	41.76	43.27	44.45
50	27.80	29.86	30.86	33.49	34.80	36.26	38.47	40.42	41.70	4?,69	44.21	45.40
51	28.54	30.63	31.64	34.31	35.64	37.11	39.35	41.32	42.61	43.61	45.15	46.36
52	29.28	31.40	32.42	35.12	36.47	37.97	40.23	42.22	43.53	44.54	46.10	47.31
53	30.03	32.17	33.21	35.94	37.31	38.82	41.10	43.12	44.44	45.47	47.04	48.27
54	30.77	32.95	33.99	36.76	38.15	39.67	41.99	44.02	45.36	46.39	47.98	49.22
55	31.52	33.72	34.78	37.59	38.99	40.53	42.87	44.93	46.28	47.32	48.93	50.18
56	32.27	34.50	35.57	38.41	39.83	41.39	43.75	45.83	47.20	48.25	49.87	51.13
57	33.03	35.28	36.37	39.24	40.67	42.25	44.64	46.74	48.12	49.18	50.82	52.09
58	33.78	36.06	37.16	40.07	41.51	43.11	45.52	47.64	49.04	50.11	51.76	53.05
59	34.54	36.85	37.96	40.90	42.36	43.97	46.41	48.55	49.96	51.04	52.71	54.01
60	35.30	37.63	38.76	41.73	43.20	44.83	47.29	49.46	50.88	51.97	53.65	54.96
61	36.06	38.42	39.56	42.56	44.05	45.70	48.18	50.37	51.80	52.90	54.60	55.92
62	36.82	39.21	40.36	43.39	44.90	46.56	49.07	51.27	52.72	53.83	55.55	56.88
63	37.59	40.00	41.16	44.23	45.75	47.43	49.96	52.18	53.64	54.77	56.49	57.84
64	38.35	40.80	41.97	45.06	46.60	48.30	50.85	53.10	54.57	55.70	57.44	58.80
65	39.12	41.59	42.78	45.90	47.45	49.16	51.74	54.01	55.49	56.63	58.39	59.76
66	39.89	42.39	43.58	46.74	48.30	50.03	52.64	54.92	56.42	57.57	59.34	60.72
67	40.66	43.18	44.39	47.58	49.16	50.90	53.53	55.83	57.34	58.50	60.29	61.68
68	41.44	43.98	45.20	48.42	50.01	51.77	54.42	56.75	58.27	59.44	61.24	62.64
69	42.21	44.78	46.02	49.26	50.87	52.65	55.32	57.66	59.20	60.37	62.19	63.60
70	42.99	45.58	46.83	50.10	51.73	53.52	56.21	58.57	60.12	61.31	63.14	64.56
71	43.77	46.39	47.64	50.95	52.59	54.39	57.11	59.49	61.05	62.25	64.09	65.52
72	44.55	47.19	48.46	51.79	53.45	55.27	58.01	60.41	61.98	63.18	65.04	66.48
73	45.33	48.00	49.28	52.64	54.31	56.14	58.90	61.32	62.91	64.12	65.99	67.44
74	46.11	48.81	50.10	53.49	55.17	57.02	59.80	62.24	63.84	65.06	66.94	68.40
75	46.90	49.61	50.92	54.34	56.03	57.90	60.70	63.16	64.76	66.00	67.89	69.37
76	47.68	50.42	51.74	55.19	56.89	58.78	61.60	64.07	65.69	66.94	68.85	70.33
77	48.47	51.23	52.56	56.04	57.76	59.65	62.50	64.99	66.63	67.88	69.80	71.29
78	49.26	52.05	53.38	56.89	58.62	60.53	63.40	65.91	67.56	68.82	70.75	72.25
79	50.05	52.86	54.21	57.74	59.49	61.41	64.30	66.83	68.49	69.76	71.70	73.22
80	50.84	53.68	55.03	58.60	60.36	62.30	65.21	67.75	69.42	70.70	72.66	74.18
81	51.63	54.49	55.86	59.45	61.22	63.18	66.11	68.67	70.35	71.64	73.61	75.14
82	52.43	55.31	56.69	60.30	62.09	64.06	67.01	69.59	71.28	72.58	74.57	76.11
83	53.22	56.13	57.52	61.16	62.96	64.94	67.92	70.52	72.22	73.52	75.52	77.07
84	54.02	56.95	58.35	62.02	63.83	65.83	68.82	71.44	73.15	74.46	76.47	78.04
85	54.81	57.77	59.18	62.88	64.70	66.71	69.73	72.36	74.08	75.40	77.43	79.00
86	55.61	58.59	60.01	63.73	65.57	67.60	70.63	73.28	75.02	76.35	78.38	79.97
87	56.41	59.41	60.84	64.59	66.45	68.48	71.54	74.21	75.95	77.29	79.34	80.93
88	57.21	60.23	61.67	65.45	67.32	69.37	72.45	75.13	76.89	78.23	80.30	81.90
89	58.02	61.06	62.51	66.32	68.19	70.26	73.35	76.06	77.82	79.18	81.25	82.86
90	58.82	61.88	63.34	67.18	69.07	71.15	74.26	76.98	78.76	80.12	82.21	83.83

91	59.62	62.71	64.18	68.04	69.94	72.04	75.17	77.91	79.69	81.06	83.16	84.79
92	60.43	63.54	65.02	68.90	70.82	72.92	76.08	78.83	80.63	82.01	84.12	85.76
93	61.23	64.36	65.86	69.77	71.70	73.81	76.99	79.76	81.57	82.95	85.08	86.73
94	62.04	65.19	66.70	70.63	72.57	74.71	77.90	80.69	82.50	83.90	86.03	87.69
95	62.85	66.02	67.54	71.50	73.45	75.60	78.81	81.61	83.44	84.84	86.99	88.66
96	63.66	66.85	68.38	72.36	74.33	76.49	79.72	82.54	84.38	85.79	87.95	89.62
97	64.47	67.69	69.22	73.23	75.21	77.38	80.63	83.47	85.32	86.74	88.91	90.59
98	65.28	68.52	70.06	74.10	76.09	78.27	81.54	84.39	86.26	87.68	89.87	91.56
99	66.09	69.35	70.90	74.97	76.97	79.17	82.46	85.32	87.20	88.63	90.82	92.53
100	66.91	70.19	71.75	75.84	77.85	80.06	83.37	86.25	88.13	89.58	91.78	93.49

N is the number of servers. The numerical column headings indicate blocking probability B in %. Table generated by Dan Dexter

Poisson Traffic Table

Maximum Offered Load Versus B and N
B is in %

N/B	0.01	0.05	0.1	0.5	1.0	2	5	10	15	20	30	40
1	.0001	.0005	.0010	.0050	.0101	.0202	.0513	.1054	.1625	.2231	.3567	.5108
2	.0142	.0320	.0454	.1035	.1486	.2147	.3554	.5318	.6832	.8244	1.097	1.376
3	.0862	.1497	.1905	.3379	.4360	.5672	.8177	1.102	1.331	1.535	1.914	2.285
4	.2318	.3552	.4286	.6722	.8232	1.016	1.366	1.745	2.039	2.297	2.764	3.211
5	1.078	1.279	1.530	1.970	2.433	2.785	3.090	3.634	4.148			
6	.7137	.9672	1.107	1.537	1.785	2.089	2.613	3.152	3.557	3.904	4.517	5.091
7	1.030	1.348	1.520	2.037	2.330	2.684	3.285	3.895	4.348	4.734	5.411	6.039
8	1.387	1.768	1.971	2.571	2.906	3.307	3.981	4.656	5.155	5.576	6.312	6.991
9	1.778	2.220	2.452	3.132	3.508	3.953	4.695	5.433	5.973	6.429	7.220	7.947
10	2.198	2.699	2.961	3.717	4.130	4.618	5.425	6.221	6.802	7.289	8.133	8.904
11	2.643	3.202	3.492	4.321	4.771	5.300	6.169	7.021	7.639	8.157	9.050	9.864
12	3.112	3.726	4.042	4.943	5.428	5.996	6.924	7.829	8.484	9.031	9.972	10.83
13	3.600	4.269	4.611	5.580	6.099	6.704	7.690	8.646	9.336	9.910	10.90	11.79
14	4.106	4.828	5.195	6.231	6.782	7.424	8.464	9.470	10.19	10.79	11.82	12.76
15	4.629	5.402	5.794	6.893	7.477	8.153	9.246	10.30	11.06	11.68	12.75	13.72
16	5.167	5.990	6.405	7.567	8.181	8.891	10.04	11.14	11.92	12.57	13.69	14.69
17	5.718	6.590	7.028	8.251	8.895	9.638	10.83	11.98	12.79	13.47	14.62	15.66
18	6.281	7.201	7.662	8.943	9.616	10.39	11.63	12.82	13.67	14.37	15.56	16.63
19	6.856	7.822	8.306	9.645	10.35	11.15	12.44	13.67	14.55	15.27	16.50	17.60
20	7.442	8.453	8.958	10.35	11.08	11.92	13.26	14.53	15.43	16.17	17.44	18.57
21	8.037	9.093	9.619	11.07	11.83	12.69	14.07	15.38	16.31	17.08	18.38	19.54
22	8.642	9.741	10.29	11.79	12.57	13.47	14.89	16.24	17.20	17.99	19.32	20.51
23	9.255	10.40	10.96	12.52	13.33	14.25	15.72	17.11	18.09	18.90	20.27	21.48
24	9.876	11.06	11.65	13.26	14.09	15.04	16.55	17.98	18.98	19.81	21.21	22.46
25	10.50	11.73	12.34	14.00	14.85	15.83	17.38	18.84	19.88	20.73	22.16	23.43
26	11.14	12.41	13.03	14.74	15.62	16.63	18.22	19.72	20.77	21.64	23.10	24.41
27	11.78	13.09	13.73	15.49	16.40	17.43	19.06	20.59	21.67	22.56	24.05	25.38
28	12.43	13.78	14.44	16.25	17.18	18.23	19.90	21.47	22.57	23.48	25.00	26.36
29	13.09	14.47	15.15	17.00	17.96	19.04	20.75	22.35	23.48	24.40	25.95	27.33
30	13.75	15.17	15.87	17.77	18.74	19.85	21.59	23.23	24.38	25.32	26.91	28.31
31	14.42	15.87	16.59	18.53	19.53	20.66	22.45	24.11	25.29	26.24	27.86	29.29
32	15.09	16.58	17.32	19.31	20.32	21.48	23.30	25.00	26.19	27.17	28.81	30.26
33	15.76	17.30	18.05	20.08	21.12	22.30	24.15	25.89	27.10	28.09	29.76	31.24
34	16.44	18.01	18.78	20.86	21.92	23.12	25.01	26.77	28.01	29.02	30.72	32.22
35	17.13	18.73	19.52	21.64	22.72	23.95	25.87	27.66	28.92	29.95	31.67	33.20
36	17.82	19.46	20.26	22.42	23.53	24.77	26.73	28.56	29.84	30.88	32.63	34.18
37	18.52	20.19	21.01	23.21	24.33	25.60	27.60	29.45	30.75	31.81	33.59	35.16
38	19.21	20.92	21.75	24.00	25.14	26.44	28.46	30.35	31.66	32.74	34.54	36.14
39	19.92	21.66	22.51	24.79	25.96	27.27	29.33	31.24	32.58	33.67	35.50	37.11
40	20.62	22.40	23.26	25.59	26.77	28.11	30.20	32.14	33.50	34.60	36.46	38.09
41	21.33	23.14	24.02	26.38	27.59	28.95	31.07	33.04	34.42	35.54	37.42	39.07
42	22.05	23.88	24.78	27.18	28.41	29.79	31.94	33.94	35.33	36.47	38.38	40.05
43	22.76	24.63	25.54	27.99	29.23	30.63	32.81	34.84	36.26	37.41	39.34	41.04

44	23.48	25.38	26.31	28.79	30.05	31.47	33.69	35.74	37.18	38.34	40.30	42.02
45	24.20	26.14	27.08	29.60	30.88	32.32	34.56	36.65	38.10	39.28	41.26	43.00
46	24.93	26.90	27.85	30.41	31.71	33.17	35.44	37.55	39.02	40.22	42.22	43.98
47	25.66	27.65	28.62	31.22	32.53	34.01	36.32	38.46	39.94	41.16	43.18	44.96
48	26.39	28.42	29.40	32.03	33.37	34.87	37.20	39.36	40.87	42.09	44.14	45.94
49	27.13	29.18	30.18	32.85	34.20	35.72	38.08	40.27	41.79	43.03	45.10	46.92
50	27.86	29.95	30.96	33.66	35.03	36.57	38.97	41.18	42.72	43.97	46.06	47.90
51	28.60	30.72	31.74	34.48	35.87	37.43	39.85	42.09	43.65	44.91	47.03	48.89
52	29.34	31.49	32.53	35.30	36.71	38.28	40.73	43.00	44.58	45.85	47.99	49.87
53	30.09	32.26	33.31	36.13	37.55	39.14	41.62	43.91	45.50	46.80	48.95	50.85
54	30.84	33.04	34.10	36.95	38.39	40.00	42.51	44.82	46.43	47.74	49.92	51.83
55	31.59	33.82	34.90	37.78	39.23	40.86	43.40	45.74	47.36	48.68	50.88	52.82
56	32.34	34.60	35.69	38.60	40.07	41.72	44.29	46.65	48.29	49.63	51.85	53.80
57	33.09	35.38	36.48	39.43	40.92	42.59	45.18	47.56	49.22	50.57	52.81	54.78
58	33.85	36.16	37.28	40.26	41.77	43.45	46.07	48.48	50.15	51.51	53.78	55.77
59	34.60	36.95	38.08	41.09	42.61	44.32	46.96	49.40	51.09	52.46	54.74	56.75
60	35.36	37.73	38.88	41.93	43.46	45.18	47.85	50.31	52.02	53.40	55.71	57.73
61	36.13	38.52	39.68	42.76	44.31	46.05	48.75	51.23	52.95	54.35	56.68	58.72
62	36.89	39.31	40.48	43.60	45.16	46.92	49.64	52.15	53.89	55.30	57.64	59.70
63	37.66	40.11	41.29	44.43	46.02	47.79	50.54	53.07	54.82	56.24	58.61	60.68
64	38.42	40.90	42.09	45.27	46.87	48.66	51.43	53.99	55.76	57.19	59.58	61.67
65	39.19	41.70	42.90	46.11	47.73	49.53	52.33	54.91	56.69	58.14	60.54	62.65
66	39.96	42.49	43.71	46.95	48.58	50.41	53.23	55.83	57.63	59.08	61.51	63.64
67	40.74	43.29	44.52	47.79	49.44	51.28	54.13	56.75	58.56	60.03	62.48	64.62
68	41.51	44.09	45.33	48.64	50.30	52.16	55.03	57.67	59.50	60.98	63.45	65.61
69	42.29	44.89	46.15	49.48	51.16	53.03	55.93	58.59	60.44	61.93	64.41	66.59
70	43.07	45.70	46.96	50.33	52.02	53.91	56.83	59.52	61.37	62.88	65.38	67.58
71	43.84	46.50	47.78	51.17	52.88	54.79	57.73	60.44	62.31	63.83	66.35	68.56
72	44.63	47.31	48.60	52.02	53.74	55.66	58.63	61.36	63.25	64.78	67.32	69.54
73	45.41	48.11	49.42	52.87	54.60	56.54	59.54	62.29	64.19	65.73	68.29	70.53
74	46.19	48.92	50.24	53.72	55.47	57.42	60.44	63.21	65.13	66.68	69.26	71.52
75	46.98	49.73	51.06	54.57	56.33	58.30	61.35	64.14	66.07	67.63	70.23	72.50
76	47.76	50.54	51.88	55.42	57.20	59.19	62.25	65.06	67.01	68.58	71.20	73.49
77	48.55	51.36	52.70	56.28	58.07	60.07	63.16	65.99	67.95	69.54	72.17	74.47
78	49.34	52.17	53.53	57.13	58.94	60.95	64.06	66.92	68.89	70.49	73.14	75.46
79	50.13	52.98	54.35	57.98	59.80	61.84	64.97	67.85	69.83	71.44	74.11	76.44
80	50.92	53.80	55.18	58.84	60.67	62.72	65.88	68.77	70.77	72.39	75.08	77.43
81	51.72	54.62	56.01	59.70	61.54	63.61	66.79	69.70	71.72	73.35	76.05	78.41
82	52.51	55.43	56.84	60.55	62.41	64.49	67.70	70.63	72.66	74.30	77.02	79.40
83	53.31	56.25	57.67	61.41	63.29	65.38	68.60	71.56	73.60	75.25	77.99	80.39
84	54.10	57.07	58.50	62.27	64.16	66.27	69.51	72.49	74.54	76.21	78.96	81.37
85	54.90	57.89	59.33	63.13	65.03	67.15	70.43	73.42	75.49	77.16	79.93	82.36
86	55.70	58.72	60.16	63.99	65.91	68.04	71.34	74.35	76.43	78.11	80.91	83.34
87	56.50	59.54	61.00	64.85	66.78	68.93	72.25	75.28	77.38	79.07	81.88	84.33
88	57.31	60.37	61.83	65.72	67.66	69.82	73.16	76.21	78.32	80.02	82.85	85.32
89	58.11	61.19	62.67	66.58	68.53	70.71	74.07	77.14	79.27	80.98	83.82	86.30
90	58.91	62.02	63.51	67.44	69.41	71.61	74.98	78.08	80.21	81.93	84.79	87.29

91	59.72	62.84	64.34	68.31	70.29	72.50	75.90	79.01	81.16	82.89	85.77	88.28
92	60.52	63.67	65.18	69.17	71.17	73.39	76.81	79.94	82.10	83.85	86.74	89.26
93	61.33	64.50	66.02	70.04	72.05	74.28	77.73	80.88	83.05	84.80	87.71	90.25
94	62.14	65.33	66.86	70.91	72.93	75.18	78.64	81.81	83.99	85.76	88.68	91.24
95	62.95	66.16	67.70	71.77	73.81	76.07	79.56	82.74	84.94	86.72	89.66	92.22
96	63.76	66.99	68.55	72.64	74.69	76.97	80.47	83.68	85.89	87.67	90.63	93.21
97	64.57	67.83	69.39	73.51	75.57	77.86	81.39	84.61	86.83	88.63	91.60	94.20
98	65.38	68.66	70.23	74.38	76.45	78.76	82.31	85.55	87.78	89.59	92.58	95.19
99	66.19	69.50	71.08	75.25	77.33	79.65	83.22	86.48	88.73	90.54	93.55	96.17
100	67.01	70.33	71.92	76.12	78.22	80.55	84.14	87.42	89.68	91.50	94.52	97.16

N is the number of servers. The numerical column headings indicate blocking probability B in %. Table generated by Dan Dexter