Menoufia University
Faculty of Electronic Engineering, Menouf
Department of Communications Engineering

A Master Thesis of

Teletraffic Analysis of the Next-Generation Integrated Terrestrial/Satellite Mobile Radio Networks

by

Waleed Eid Al-Hanafy

(B.Sc.)

ABSTRACT

As mobile service demands increase dramatically, interest in cellular system structure with hierarchical terrestrial/satellite architecture has emerged. Without satellite participation, terrestrial cellular systems would be primarily restricted to regional service. For the network to have seamless radio coverage and sufficient capacity to accommodate anticipated high teletraffic demand, integration of satellite network and terrestrial cellular system is indispensable. In this research project, a space/terrestrial mobile radio communication network with multiple hierarchical cellular overlays is considered. In the lowest hierarchical level, microcells serve the highest teletraffic density, while overlaying macrocells serve both calls from areas that are difficult to be covered by microcells, as well as overflow traffic from microcells. At the highest hierarchical level, satellites focus their spotbeams to serve satellite-only users sparsely distributed and act as teletraffic relief for the terrestrial segment. At each hierarchical level different priority schemes are used to privilege handoff requests. Reserved channel scheme (RCS) is applied in the microcell layer, both RCS and sub-rating scheme (SRS) are used in the macrocell layer, while in the spotbeam cell layer, RCS, SRS, and queuing priority scheme (QPS) are implemented. An analytical teletraffic model is developed to evaluate the proposed architecture. Numerical results are presented and discussed for the new call blocking, handoff failure, forced termination and noncompletion probabilities. The work presented in the thesis will help understanding the next-generation communication network and thereby allow better engineering of its resources.

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Note on Publication

A paper extracted from the research work of the MSc thesis

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Authors: **Sami El-Dolil, Mostafa Nofal, and Waleed Al-Hanafy**

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List of Symbols

K	cluster size
C/R	carrier to interference ratio
γ	propagation path loss exponent
D/R	frequency reuse distance
A_s	satellite coverage area
α	minimum elevation angle
θ	earth central angle
h	satellite altitude
R_e	radius of the earth
C_m	no. of microcells per macrocell
C_M	no. of macrocells per spotbeam cell
N_m	no. of channels per microcell
N_{mh}	no. of channels reserved for handoff per microcell
N_M	no. of channels per macrocell
N_{Mo}	no. of channels reserved for handoff overflow per macrocell
N_{Mh}	no. of channels reserved for handoff per macrocell
N_s	no. of channels per spotbeam cell
N_{so}	no. of channels reserved for handoff overflow per spotbeam cell
N_{sh}	no. of channels reserved for handoff per spotbeam cell
λ_m	new call rate per microcell
λ_{mh}	handoff call rate per microcell
λ_M	new call rate per macrocell
λ_{Mon}	new call rate overflowed to macrocell
λ_{Moh}	handoff call rate overflowed to macrocell
λ_{Mh}	handoff call rate per macrocell
λ_s	new call rate per spotbeam cell
λ_{son}	new call rate overflowed to spotbeam cell
λ_{soh}	handoff call rate overflowed to spotbeam cell
λ_{sh}	handoff call rate per spotbeam cell
$\bar{T}_M$	average call duration time = $1/\mu_M$
$\bar{T}_{n1}$	average residing time of a new call in microcell = $1/\mu_{n1}$
$\bar{T}_{h1}$	average residing time of a handoff call in microcell = $1/\mu_{h1}$
$\bar{T}_{n2}$	average residing time of a new call in macrocell = $1/\mu_{n2}$
$\bar{T}_{h2}$	average residing time of a handoff call in macrocell = $1/\mu_{h2}$
$\bar{T}_{n3}$	average residing time of a new call in spotbeam cell = $1/\mu_{n3}$
$\bar{T}_{h3}$	average residing time of a handoff call in spotbeam cell = $1/\mu_{h3}$

$\bar{T}_q$	average queuing time within the overlapping area for the spotbeam cell = $1/\mu_q$
$\bar{T}_{H1}$	average channel holding time in the microcell = $1/\mu_{H1}$
$\bar{T}_{H2}$	average channel holding time in the macrocell = $1/\mu_{H2}$
$\bar{T}_{H3}$	average channel holding time in the spotbeam cell = $1/\mu_{H3}$
P_{N1}	probability that a successfully initiated call in the microcell requires a handoff
P_{H1}	probability that a handoff call in the microcell will require more handoff
P_{N2}	probability that a successfully initiated call in the macrocell requires a handoff
P_{H2}	probability that a handoff call in the microcell will require more handoff
P_{N3}	probability that a successfully initiated call in the spotbeam cell requires a handoff
P_{H3}	probability that a handoff call in the spotbeam cell will require more handoff
P_{Bm}	new call blocking probability in the microcell
P_{fhm}	handoff failure probability in the microcell
P_{BMon}	overflowed new call blocking probability in the macrocell
P_{BMoh}	overflowed handoff call blocking probability in the macrocell
P_{BM}	new call blocking probability in the macrocell
P_{fhM}	handoff failure probability in the macrocell
P_{Bson}	overflowed new call blocking probability in the spotbeam cell
P_{Bsoh}	overflowed handoff call blocking probability in the spotbeam cell
P_{Bs}	new call blocking probability in the spotbeam cell
P_{fhs}	handoff failure probability in the spotbeam cell
P_{Bdo}	overall blocking probability of the dual-mode users within microcell
P_{Bdw}	weighted blocking probability of the dual-mode users
P_{fhdo}	overall handoff failure probability of the dual-mode users within microcell
P_{fhdw}	weighted handoff failure probability of the dual-mode users
P_{Bto}	overall blocking probability of the terrestrial-only users within microcell
P_{Btw}	weighted blocking probability of the terrestrial-only users
P_{fhto}	overall handoff failure probability of the terrestrial-only users within microcell
P_{fhtw}	weighted handoff failure probability of the terrestrial-only users
P_{Bso}	overall blocking probability of the satellite-only users
P_{Bsw}	weighted blocking probability of the satellite-only users
P_{fhso}	overall handoff failure probability of the satellite-only users
P_{fhsw}	weighted handoff failure probability of the satellite-only users
P_{Fd}	overall forced termination probability of the dual-mode users within a microcell
P_{Ft}	overall forced termination probability of the terrestrial-only users within a microcell
P_{Fs}	overall forced termination probability of the satellite-only users
P_{ncd}	noncompleted call probability of the dual-mode users
P_{nct}	noncompleted call probability of the terrestrial-only users
P_{ncs}	noncompleted call probability of the satellite-only users

Contents

Chapter 1

Introduction

The ultimate aim for next-generation mobile radio network is to enable mobile users to initiate and receive calls with any one, anywhere and at anytime using a single telecommunication device. The terrestrial-based cellular system is a high-density architecture that is able to provide wireless connections to regions with high teletraffic demand. For sparsely populated and less-privilege areas, implementing terrestrial systems is not economically feasible. Moreover, aeronautical and maritime communities can not be served by terrestrial systems. Therefore, terrestrial systems have limited coverage and expensive infrastructure. On the other hand, satellite systems can provide wide-area or global coverage. They do an excellent job of providing connections everywhere, but can not compete with terrestrial architectures in providing high capacity due to their large created cells on the earth's surface. It is thus evident that if the future global telecommunication network is to have seamless radio coverage and sufficient capacity to accommodate anticipated high teletraffic demand, integration of satellite network and terrestrial cellular system is indispensable.

For the integrated satellite/terrestrial mobile radio system, the network is arranged in a hierarchical architecture. The terrestrial segment consists of microcells and macrocells. Overlaying macrocells cover spots that are difficult in radio propagation for microcells and provide overflow channels for clusters of microcells. The satellite segment, on the other hand, will extend the radio coverage regions where terrestrial coverage deemed uneconomical or impractical and works as well as a backup facility for overflow traffic from the terrestrial segment. The situation, then, where satellite-only, terrestrial-only and dual-mode terminal coexist can be envisaged. From the teletraffic point of view, user mobility in this hierarchical architecture results in more complex mobility management due to the horizontal handoff from cell-to-cell in the same level as well as the vertical handoff to a higher level in the architecture. The user mobility results in reduction of the resource occupation time compared to the total cell duration. In addition, the radio resources of a cell in any level should cater for both new calls originated in its coverage area and incoming handoff requests from any neighbouring cell in the same level or underlay cell in the lower level. An abnormal call termination due to lack of resources in the target cell should be avoided as possible by providing different priority schemes at any hierarchical level.

1.1 Objective of the Thesis

A multiple hierarchical cellular structure is proposed to handle the teletraffic load resulting from different user densities. In the lowest hierarchical level, microcells serve the highest teletraffic density, while overlaying macrocells serve both calls from areas that are difficult to be covered by microcells, as well as overflowed traffic from microcells. At the highest hierarchical level, nongeostationary satellites focus their spotbeams to serve satellite-only users sparsely distributed and act as teletraffic relief for the terrestrial segment. At each hierarchical level different priority schemes are used to privilege handoff requests. Reserved channel scheme (RCS) is applied in the microcell layer, both RCS and sub-rating scheme (SRS) are used in the macrocell layer, while in the spotbeam cell layer, RCS, SRS, and queuing priority scheme (QPS) are implemented. An analytical teletraffic model is developed to evaluate the proposed architecture. Numerical results are presented and discussed for the new call blocking, handoff failure, forced termination and noncompleted call probabilities.

1.2 Organization of the Thesis

The thesis comprises seven chapters. In chapter 2, an overview of mobile radio communications is introduced. The evolution and the main concepts of the network design of both cellular mobile radio systems and satellite networks are described. Also the need for integration of the two systems is briefly investigated in order to reach a unified global system.

In chapter 3, the classical teletraffic theory and its associated terms are presented and accompanied with analysis of its formulae and parameters. Also, an extension of this classical theory to accommodate the handoff process resulting from user's mobility in the cellular structure is introduced.

The multilayered systems with hierarchical structures including terrestrial systems represented by microcells and macrocells, and satellite systems represented by spotbeam cells are integrated to attain the desired unified global mobile communication system. Also the mobility management describing this integration is introduced in chapter 4.

The teletraffic analysis of the multiple hierarchical cellular communication system with different handoff priority schemes including, reserved channel scheme (RCS), sub-rating scheme (SRS), and queuing priority scheme (QPS), is introduced and evaluated in chapter 5.

Chapter 6 encompasses the numerical results for the performance measures of the proposed model obtained for nominal system parameters. These are followed by an analysis of the proposed model performance under some parameters variations to evaluate the validity of the proposed architecture under different circumstances.

Our conclusion and future trends toward advanced global mobile communication system that makes use of the software radios are presented in chapter 7.

Chapter 2

Overview of Mobile Radio Systems

2.1 Introduction

Perhaps the clearest constituents in all of the wireless personal communications activity are the desire for mobility in communications and the companion desire to be free from tethers i.e., from physical connections to communications networks. These desires arise from the very rapid growth of mobile technologies that provide primarily two-way voice services, even though economical wireline voice services are readily available [1].

The phenomenal growth in the mobile communications industry has been one of the success stories of the last decade. With almost 5 million new mobile users per month the global market for mobile communications is forecasted to grow from today's figure of 200 million to around 2.4 billion users by 2015 [2]. Wireless access will overtake fixed access to global telecommunications early in the 21st century. Mobile communication technology has evolved along a long path, from the simple first-generation analog products designed for business use to second- generation digital wireless telecommunication systems for residential and business environments. Entertainment, video, banking and the like are all separate entities. In the future it is envisioned that a complete personal communication system (PCS) will exist. These will enable users to economically transfer and receive any form of information anywhere and at anytime. This will encourage the use of mobile phone as a "life-style portal" rather than just a voice communications device. In order to accomplish this, a new generation of mobile communications systems is required. This new generation of mobile systems will be known as third-generation mobile communications systems [2].

PCS employs a small handset that allows a user to communicate with anyone, in a variety of formats–voice, data, image, and full motion video–from virtually any geographic location, whether from home, the office, or on the road. To do this, the PCS relies on access to a variety of networks including the public switched telephone network, wireless and satellite systems, the integrated service digital network, and the terrestrial mobile systems. The key element that forms the basis for this mobility is a single personal telecommunications number, or PTN. Armed with this number, the user has the unprecedented capability of global roaming [3].

In this chapter an overview of mobile radio communications is introduced. The evolution as well as the main design and network concepts of both cellular mobile radio systems and satellite networks are described. Also the need for integration between the two systems is briefly investigated in order to reach a unified global system.

2.2 Evolution of Mobile Communication Systems

Radio telephones have been used for decades, but were not widely available because of limited system capacity. The breakthrough on the capacity problem came with the developments of the cellular concept, which allows frequency reuse. Since then, the use of wireless communications has grown explosively. The evolution of wireless systems can be divided into three mobile communication generations.

2.2.1 First generation

The first generation of mobile systems was characterized by analog techniques such as the British total access communication system (TACS), American advanced mobile phone system (AMPS), Japanese mobile phone system (JMPS), Nordic mobile telephone (NMT), and so forth. Concerning mobile satellite systems (MSS), they were characterized by global beam features and rather large user terminals, although transportable in principle [4]. The large increase in capacity required to feed demand implied a corresponding increase in difficulties of enlarging the networks. In addition to the capacity bottleneck, the utility of first generation analog systems was diminished by the proliferation of incompatible standards in Europe. The same mobile telephone frequencies could not be used in different European countries. These limitations as well as digital communication technologies become mature enough for commercial use provided motivations for the development of second generation systems [2].

2.2.2 Second generation

The second generation digital wireless system is built in the late 1980's and the 1990's. The main feature of this generation is the implementation of digital technology. The system capacity is several times higher than the traditional analog system. More service features are introduced, the service quality is improved, and the service cost is significantly reduced [3].

Telepoint and cordless telephone systems (e.g., CT2, CT3, Digital European cordless telecommunications (DECT)), paging (European radio messaging system (ERMES)), cellular networks such as global system for mobile communications (GSM), digital cellular system at 1800 MHz (DCS-1800) or personal communication networks (PCN's), as well as multiple beam mobile satellite systems servicing briefcase lap-top size terminals, all are examples of second generation personal communication systems. Each one being based on technologies designed and optimized for specific traffic scenarios. Telepoint/Cordless systems match the requirement for wireless communications in very high traffic density environments (residential, in-building, public transportation, etc.). Cellular networks like GSM, are the winning choices for high-to-medium traffic density areas (urban, suburban, possibly rural environments). Satellite communication networks play their role wherever the terrestrial networks are neither competitive (low traffic density), nor applicable (maritime and aeronautical services), or even undeveloped at all [4].

2.2.3 Third generation

The drawback of existing mobile systems is that they are not capable of supporting the high bandwidth applications that characterize the kind of services users will demand as we move into the next century. With the trend towards globalization of the world's economy it is desirable that communications take place globally providing 'communications anywhere-anytime' [2]. Despite the fact that some of the more recent systems work on similar principles, most of them are incompatible with each other. Thus, with a universal personal telecommunication (UPT), user should be able to utilize personal services independently of the kind of network access (PSTN, cellular, satellite, etc.) [4]. It is clear that a new generation of wireless services is required which can address the above problems. This new generation of wireless services is described as third generation mobile communications systems [2] as shown in Table 1 and Fig. 2.1. Its purpose is to provide wireless access to the global telecommunications infrastructure through both satellite and terrestrial systems, serving fixed and mobile users in public and private networks. Although most discussions on PCS have focused on the terrestrial system, we believe that the mobile satellite systems will also play a significant role. Satellite service complements the existing terrestrial systems by providing coverage in geographical areas where the terrestrial component cannot physically or economically provide coverage, e.g., coverage of ships, aircraft, and users in rural areas. In addition, it is crucial to support the global roaming feature of PCS. The key problem in satellite system design is the efficient use of two critical satellite resources (bandwidth and power). The cellular concept is also introduced in the satellite system to increase the system capacity [3]. The European version of the third generation systems is known as the Universal Mobile Telephone System (UMTS). UMTS will encourage the use of the phone as a 'lifestyle portal' rather than just a voice communications device.

It will include improvements in batteries, integrated circuits, introduction of flat screens, camera, voice recognition, speaker verification systems, and end-to-end encryption. It is aimed to be lunched in 2002-2005 [2].

2.3 Design Concepts of Cellular Mobile Radio Systems

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

Table 2.1: Comparison between the three mobile communications generations.

Time	First generation 1970's-1980's	Second generation 1980's-1990's	Third generation Year 2000+
Service	• Wireless voice service	• Advanced wireless voice services • Advanced wireless data services	• integrated wireless voice, data, and imaging • Advanced wireless data services, e.g., full-motion video
Technology	• Analog cellular and cordless technology • Macrocellular	• Digital cellular and cordless technology • Microcellular and picocellular • Intelligent base station technology	• Broader bandwidth radio channels • Higher frequency spectrum utilization • Advanced intelligent network technology

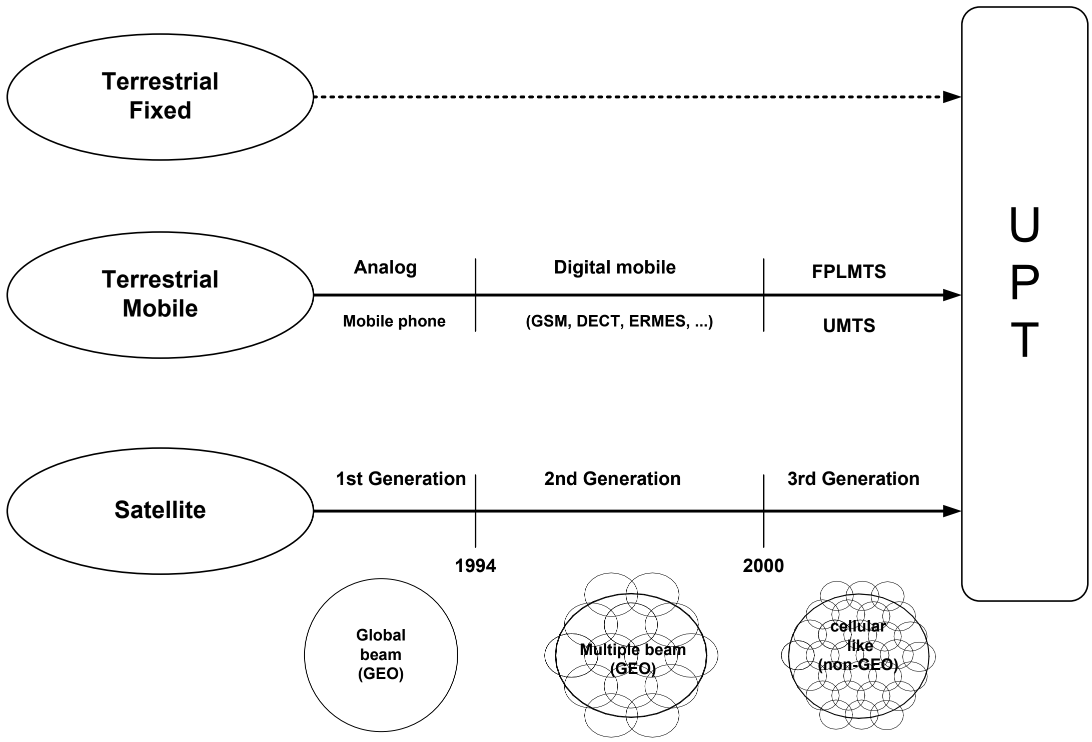


Figure 2.1: Evolution of terrestrial and satellite-based networks.

"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 areas [5]. In the following subsections the basic design concepts of cellular mobile radio systems are introduced.

2.3.1 Frequency reuse

The basic idea of the cellular concept is *frequency reuse.* It represents the core concept of the cellular mobile radio system in which the same set of channels can be reused in different geographical locations sufficiently apart from each other so that *cochannel interference* be within tolerable limits. The set of channels available in the system is assigned to a group of *cells* constituting the *cluster.* Cells are assumed to have a *regular hexagonal* shape and the number of cells per cluster determines the *repeat pattern.* Because of the hexagonal geometry only certain repeat patterns can tessellate. The number K of cells per cluster is given by

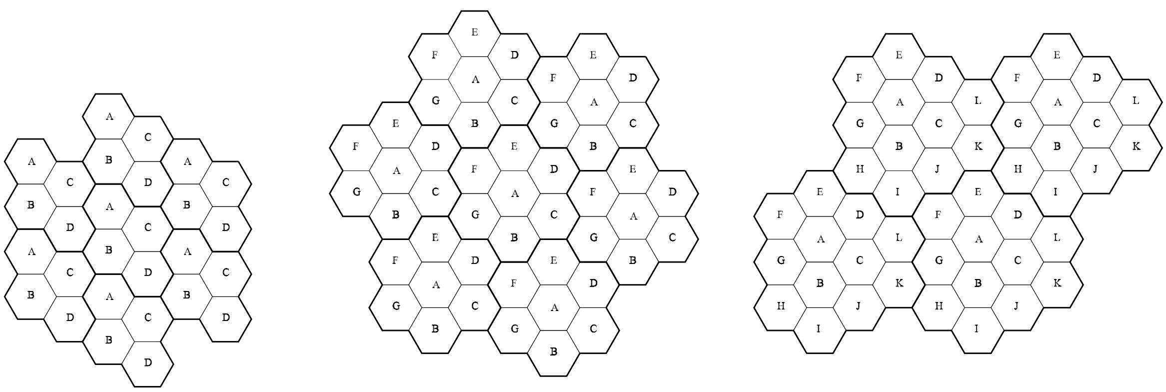
$$K = i^2 + ij + j^2, \tag{2.1}$$

where i and j are integers. From (2.1) we note that the clusters can accommodate only certain numbers of cells such as 1, 3, 4, 7, 9, 12,$\cdots$. The number of cells per cluster is intuitively related with system capacity as well as with transmission quality. The fewer cells per cluster, the larger the number of channels per cell (higher traffic carrying capacity) and the closer the cocells (potentially cochannel interference). A sample of cell reuse patterns is shown in Fig. 2.2.

An important parameter of a cellular layout relating these entities is the frequency reuse ratio (D/R), sometimes called the cochannel interference reduction ratio, where D is the distance between cocells and R is the cell radius. In a hexagonal geometry it is easy to show that

$$D/R = \sqrt{3K}\,. \tag{2.2}$$

The carrier-to-interference ratio (C/I) is an important parameter in the cellular concept that sets a limit to the available number of channels per cell and consequently determines



(a) $K = 4$ (b) $K = 7$ (c) $K = 12$

Figure 2.2: The K-cell reuse pattern.

the system capacity as demonstrated below. Assuming that the local noise level is much less than the interference level and can be neglected. Then, C/I can be expressed as

$$\frac{C}{I} = \frac{R^{-\gamma}}{\sum_{n=1}^{n_i} D_n^{-\gamma}}, \tag{2.3}$$

where γ is a propagation path-loss slope determined by the actual terrain environment. In a real mobile radio medium γ usually lies between 2 and 5 depending on the actual conditions, and always assumed to be 4, and n_i is the number of interfering cells which range from 1 for 60° directional antennas to 6 for omnidirectional cells. Assuming that γ is equal to 4 and all D_n in (2.3) are the same as D, then we can write

$$\frac{C}{I} = \frac{(D/R)^4}{n_i} = \frac{(3K)^2}{n_i}\,. \tag{2.4}$$

If the total allocated spectrum is B_T Hz and the channel bandwidth is B_C Hz, the available number of channels per cell N is given by

$$N = \frac{B_T}{B_C K}\,. \tag{2.5}$$

Then from (2.4) and (2.5), N can be obtained by

$$N = \frac{B_T}{B_C\sqrt{\frac{n_i}{9}(C/I)}}\,. \tag{2.6}$$

From (2.6) it is clear that to attain accepted voice quality C/I the number of channels per cell is decreased.

2.3.2 Cell splitting

The motivation behind implementing a cellular mobile system is to improve the utilization of the allocated spectrum. The frequency reuse scheme is one concept, and cell splitting is another concept. There are two configurations of cell splitting as shown in Fig. 2.3 depending on whether the original cell site is used or not [6].

$$\text{new cell radius} = \frac{\text{old cell radius}}{2}\,. \tag{2.7}$$

Then based on Eq. (2-7), the following equation is true.

$$\text{new cell area} = \frac{\text{old cell area}}{4}\,. \tag{2.8}$$

Let each new cell carries the same maximum traffic load of the old cell; then, in theory,

$$\frac{\text{new traffic load}}{\text{unit area}} = 4 \times \frac{\text{traffic load}}{\text{unit area}}\,. \tag{2.9}$$

Therefore, the carried traffic per unit area after splitting is four times that before splitting. If the splitting process is carried out m times, the final traffic load per unit area is related to the original traffic load per unit area as

$$\frac{\text{final traffic load}}{\text{unit area}} = 4^m \times \frac{\text{traffic load}}{\text{unit area}}\,. \tag{2.10}$$

2.3.3 Sectorization and trunking efficiency

Sectorization is the technique of splitting the omnidirectional cell with central BS into a number of sectors by using directional antennas. Spectrum efficiency is an important para-

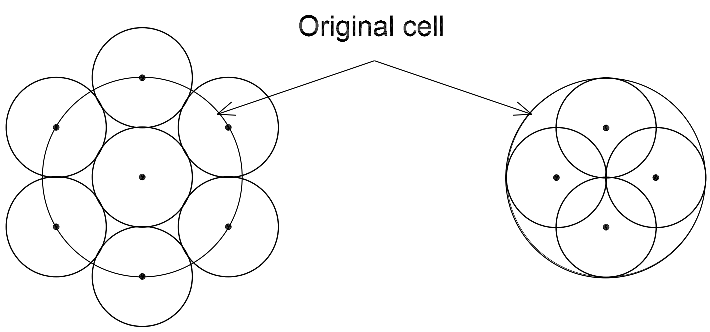


Figure 2.3: The original cell site is used in the Fig. to the left while isn't in the Fig. to the (right).

meter in the design of cellular systems. It gives a measure of how much traffic a system can carry per unit frequency per unit area [7] as

$$\text{Spectrum Efficiency} = \frac{\text{Erlang}}{\text{BW} \times \text{area}}. \tag{2.11}$$

For a given cluster size, sectorizing a cell produces two effects. First, it reduces cochannel interference. Because of the front-to-back ratio of the antenna gain, the number of stations that are interfered with by a particular base station is reduced as shown in Fig. 2.4. As a result, the C/I ratio is improved. Second, sectorization divides the cell into smaller sectors. Since the given amount of spectrum or the available channels are now distributed into smaller sectors instead of a single cell, trunking efficiency is reduced. It can be shown that higher spectrum efficiency is achieved by reducing the cluster size in a sectorized cellular system without lowering the C/I ratio below the minimum requirement [7]. From Eq. (2-4) to maintain a C/I ratio of at least 18 dB, an omnidirectional system ($n_i = 6$) requires $K = 7$, a three-sector system ($n_i = 2$) requires $K = 4$, and a six-sector system ($n_i = 1$) requires $K = 3$.

2.3.4 Handoff mechanism

The final obstacle in the design of the cellular radio system involved the problem of handoff when the mobile station (MS) moves out of the coverage area of a given cell site, the reception becomes weak. At this point, the cell site in use requests a handoff. The system switches the call to a stronger frequency channel in a new site without interrupting the call or alerting the user. The call continues as long as the user is talking, and the user doesn't notice the handoff at all [5].

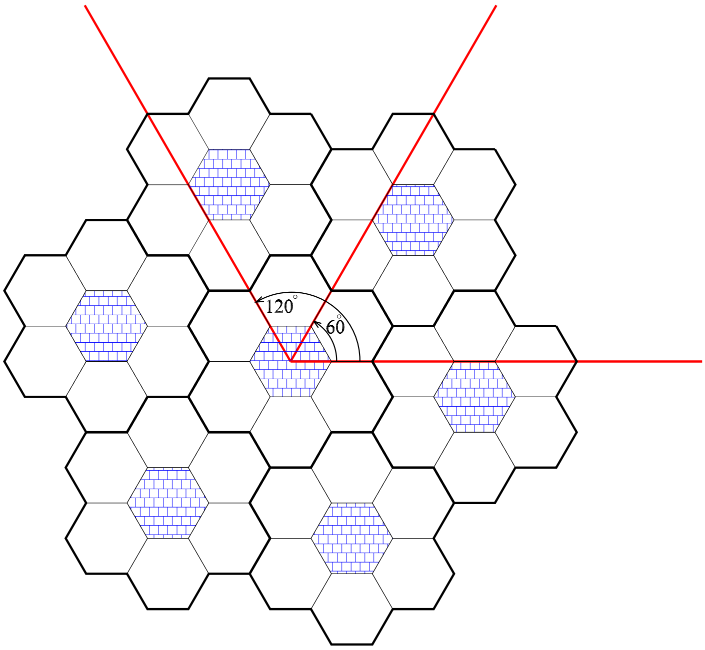


Figure 2.4: Omnidirectional sectorized cellular system and cochannel interferers.

2.4 Elements of Cellular Mobile Radio Systems

A cellular system consists of essentially a network of cells, each has its own base station which makes the radio connection to a moving station. The base stations of a cluster are connected together and also to a radio operating mobile switching center (MSC) by a dedicated permanent link, comprising speech circuits and control data link. MSC is connected to a public switching telephone network (PSTN) to give access to and from land customers. MSCs within the cellular radio network are connected together by speech and data circuits to allow calls to be forward across the cellular network. By this way a complete cellular network can be built up to give continuous radio coverage over a wide geographical area as shown in Fig. 2.5. Most of cellular networks have similar structure with three major system elements are as follows.

2.4.1 The mobile station (MS)

The mobile unit represents the interface between the user and the mobile radio system when he/she wishes to place or receive a call. A microprocessor-based controller within each mobile unit conducts the signalling, radio control, and customer alerting functions. The MSs can

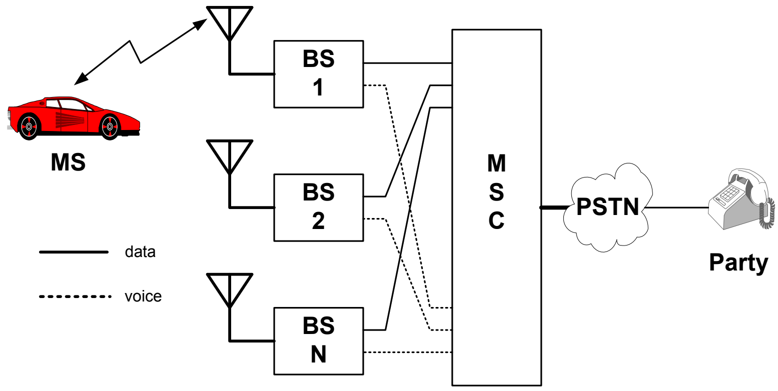


Figure 2.5: General view of cellular communication system.

take several forms ranging from vehicle mounted mobiles, through transportable units to handheld portable units.

2.4.2 The base station (BS)

Each BS contains a group of low-power transceiver that communicate with mobiles in its coverage area over the channels assigned to it. The BS processes the signals to make them suitable for transmission between the land-line network and the radio network for all mobile telephones communicating with it [8]. This requires real-time control, which is accomplished with stored-program control technique. In addition, the BS performs other control and signalling functions such as call set-up, call supervision, mobile locating, handoffs, and call termination [9].

2.4.3 The mobile switching center (MSC)

MSC handles the traffic to and from the MSs via the BSs as well as the interfacing of the cellular system to the PSTN. A grid of BSs dispersed through out the service area are connected and controlled by the MSC. It is a computer-controlled telephone exchange especially designed to serve as a central coordinator of the cellular system. It administers radio channel assignment and analyzing mobile location and signal strength data to determine when it would be advisable for the mobile to handoff to a new cell. The MSCs are linked together with digital circuits forming a fully interconnected network. The MSCs connect to the land-line network at a large number of points in order to distribute the traffic load and minimize the impact of any failures on call handling.

2.5 Space-based Systems

Due to the large coverage area offered by a satellite beam, which provides equal priority coverage for all areas of population density, the satellite component can be used to complete the coverage beyond the terrestrial network. Furthermore, aeronautical and maritime users may be solely dependent on the satellite component for the provision of services [10]. Satellite-based mobile communications have been going through an evolutionary change in the past 10 years, starting with the Inmarsat-type of mobile communications with the satellite in geostationary earth orbit (GEO) where initially global beams are used to provide services to ships at sea. In 1996, Inmarsat lunched two (of five) Inmarsat 3 satellites which produced global spot beams where the earth's disk is divided into large coverage areas serviced by individual spot beams. For the same satellite-transmitted power, the spot beams provide considerably greater effective isotropic radiated power (EIRP) than global beams. This era was followed by satellites in GEO providing several spot beam type services to terrestrial mobile units, either in vehicles or suitcase-size earth terminals. With the reasonably high EIRP laid down by the satellite, the mobiles can use medium-gain directional antennas for both data reception and voice service. However it is not able to supply service to handheld transceivers.

The next phase in mobile communications, which now borders on PCS, involves handheld transceivers characterized by very poor performance structure with power output in the order of tens of milliwatts and antenna gains in the order of 0 to 3 dB. In this application, satellites in low earth orbit (LEO) (altitudes 1,000 km) and medium earth orbit (MEO) (altitudes 10,000 km) are emerging which will lay down multiple spot beams similar to cellular structures in terrestrial cellular systems. Here, however, the cells (spot beams) have motion as the satellite flies over, and the mobile is basically stationary when compared with the rapidly moving spot (cellular) beams. It is also possible for the spot beams to be programmed to continuously searchlight the terrestrial service areas and remain fixed similar to their terrestrial cellular counterparts. This, of course, requires a more complicated antenna such as a phased array or mechanically slewed antenna and/or altitude control of the satellite bus [11].

2.5.1 Satellite orbits

An orbit is a circular path in space occupied by an object, moving in a direction parallel to the surface of the planet, that has a forward velocity sufficient to create an outward thrust (centrifugal force) equal to the gravitational pull of the planet it orbits. The plane of the orbit must pass through the center of the object to be orbited. There are several orbital constellations proposed for satellite communications, these include GEO, LEO and MEO. The choice of the orbital altitude is driven by the orbital environment and the estimated cost of the proposed constellation [12]. The relative amounts of earth coverage afforded by each one are shown in Fig. 2.6, it is clearly noted that the higher the distance from the earth's surface the larger the afforded coverage area.

The position of satellites relative to the service area is of crucial importance for the coverage, service quality, price and complexity of the overall network. When a satellite encompasses the earth in 24-hr. periods, the term *geosynchronous* orbit has been used. An orbit that is inclined with the respect to the equatorial plane is called an inclined orbit; an orbit with a 90° inclination is called a *polar* orbit. A circular geosynchronous orbit over the equatorial plane (0° inclination) is known as *geostationary* orbit, since from any point at the surface of the earth the satellite appears to be stationary; this orbit is particularly suitable for the land mobile services at low latitudes and for maritime and aeronautical services at

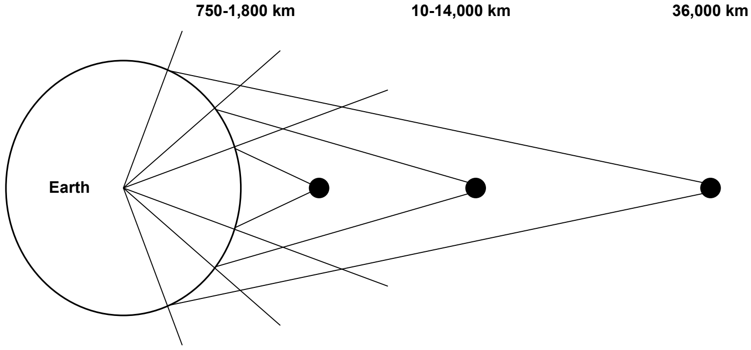


Figure 2.6: The relative amounts of earth coverage afforded by satellites.

latitudes of <80°. An elliptical geosynchronous orbit with the inclination angle of 63.4° is known as *tundra* orbit. An elliptical 12-hr. orbit with the inclination angle of 63.4° is known as *Molniya* orbit. Both tundra and Molniya orbits have been selected for the coverage of the northern latitudes and the area around the north pole; for users at those latitudes the satellites appear to wander around the zenith for a prolonged period of time. The coverage of a particular region (regional coverage) and the whole globe (global coverage) can be provided by different constellations of satellites including those in inclined and polar orbits [1].

2.5.2 GEO Vs LEO satellites

The success of satellite communications from geostationary orbit has not removed all the objections, nor has it eliminated the advantages of other orbits for some purposes.

A significant objection to GEO is the propagation delay, which is unavoidable because of the great distance and finite velocity of light. The altitude of the GEO is 35,786 km. Thus the one-way propagation delay, including the up-link and the down-link, is between 240 and 270 ms. On a typical international connection the, the round trip delay is about 0.6 s. Its effect on a voice conversation can be distracting at best and, at worst when aggravated by echo at either end of the line, can make conversation almost impossible. For digital data transmissions the delay inhibits the use of error correcting protocols that require error detection and selective retransmission of the errored blocks. The delay to low- and medium-altitude orbits is much less and the effects are either negligible or are easily accommodated.

The second fundamental objection to GEO is the lack of coverage at far northern and southern latitudes. There is considerable theory and experiment to suggest that elevation angles higher than 40° are desired for consistent service. These elevations are simply unachievable from GEO even at latitudes as close to the equator as 45°. Many of the capitals of Europe, including Paris, London, Berlin, Warsaw, and Moscow, are north of this latitude. On the other hand, high angles of elevation from inclined or polar orbiting LEO constellations are easily attained.

The requirements of short time delay and high angles of elevation, together with spacecraft design constraints such as antenna size, lead to the choice of LEO or MEO for mobile satellite communications for the majority of the proposed systems. However, the orbit altitude cannot be freely chosen because of the existence of the Van Allen radiation belts. There are two torroidal belts, centered on the earth's geomagnetic axis, at altitudes ranging from about 1,500 to 5,000 km and from 13,000 to 20,000 km [13].

2.5.3 Satellite constellations

In order to provide continuous coverage a constellation of satellites must be deployed, and the number depends on the altitude of the satellites and the ground transceiver antenna beam minimum elevation angle required to reduce losses due to shadowing and blockage. Intuitively, one can see that the higher the orbital altitude (within limits), the greater the viewing area and the fewer the number of satellites needed to cover the earth on a continuous basis. Similarly, the higher the elevation angle, the greater the number of satellites required. More satellites are packed into the orbits since their viewing angles have been restricted to satisfy minimum elevation angles. From Fig. 2.7 the coverage area of a single satellite is dependent on the satellite altitude, h, and the minimum elevation angle, α, as previously mentioned from the following equation

$$A_s = 2\pi R_e^2(1 - \cos\theta), \tag{2.12}$$

where R_e is the radius of the earth, and θ is the earth central angle and is given by

$$\theta = \cos^{-1}\left(\frac{R_e \cos\alpha}{R_e + h}\right) - \alpha \tag{2.13}$$

From Equations (2-12) and (2-13), we can plot the coverage area versus the satellite altitude with different elevation angle as shown in Fig. 2.8.

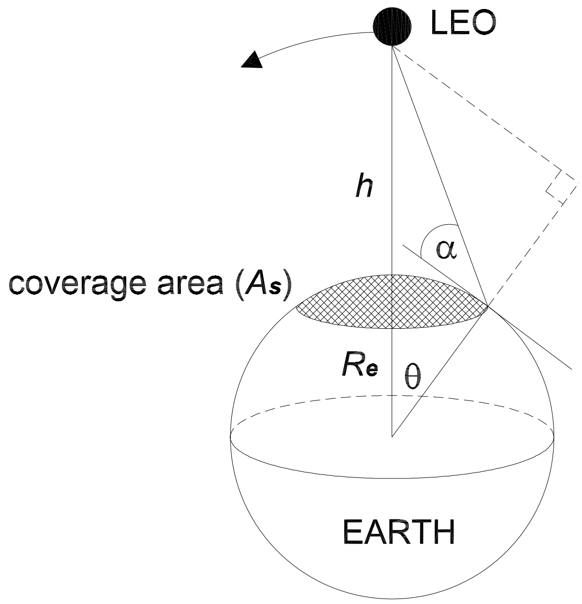


Figure 2.7: The coverage area of the earth's surface within the visibility of LEO satellite.

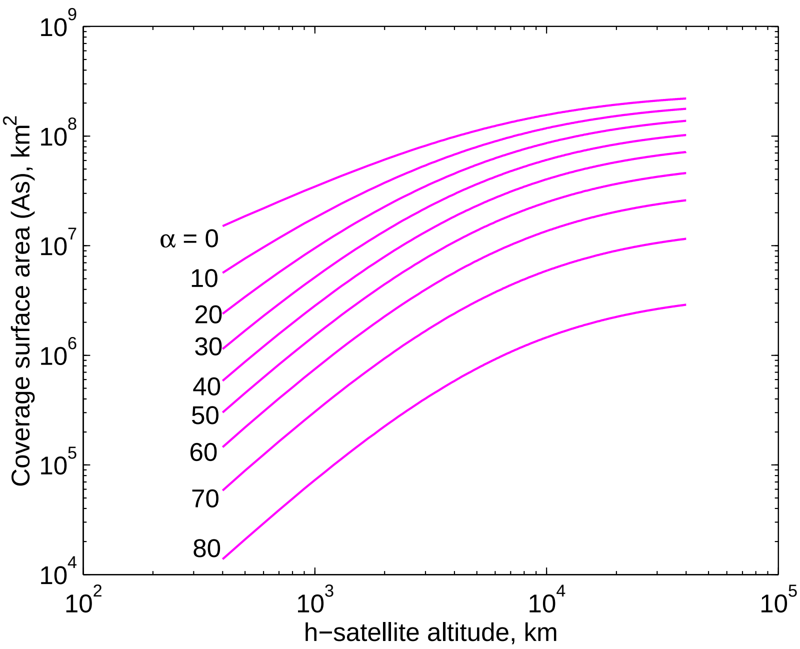


Figure 2.8: The coverage area in km^2 versus the orbit altitude in km for different minimum elevation angles.

Two schools of thought have evolved in constellation design for LEO and MEO. One is deploying satellites in multiple polar orbits (90° inclination) or near polar orbit. Research in this area has been performed by several investigators (Beste, Adams, and Rider) [11].

The other approach has considered satellites in several planes but in inclined orbits. These studies have been completed by Ballared and Walker [11].

Because of the altitude and the finite antenna aperture sizes possible on spacecraft, the spot beams will encompass large areas (hundreds of miles in diameter) which can be referred to as megacells, as compared to macrocells or microcell of terrestrial cellular systems. Terrestrial cells may range from 1 to 20 miles in diameter. It is of interest and important to note that the satellite spot beams approximate contiguous cellular clusters as in terrestrial systems, but the performance parameters are not quite the same for many reasons. First, the satellite cellular signal received at the ground receiver does not manifest the inverse 4th power loss attenuation commonly used in terrestrial cellular systems. Second, in terrestrial cellular systems there is generally no line-of-sight propagation, where in satellite applications generally there is line-of-sight propagation, and the signal will have a strong dominant component (plus random components due to multipath). Finally, from an interference point of view, spot beams do not confine their energy to a single spot or cell but wiggle into other cells because of the attendant sidelobes of the satellite beam(s).

2.6 Mobile Radio Channel Characteristics

The radio channel places fundamental limitations on the performance of mobile communication systems. Unlike wired channels that are stationary and predictable, radio channels are extremely random and do not offer easy analysis. In fact, modeling the radio channel has historically been one of the challenging parts of any radio system design and is typically done in a statistical fashion, based on measurements made specifically for an intended communication system [1]. The propagation between the transmitting antenna and the mobile unit antenna is over several paths, namely, the line-of-sight path and the paths due to scattering caused by reflections from and diffractions around obstructions. These interfering signals produce a complex standing wave pattern of varying field strength, with maxima and minima being of the order of a quarter wavelength apart. As a result of the vehicle movement through this standing wave pattern, the received signal experiences random variations in both amplitude and phase. Fades of 40 dB or more below the mean signal level are common, with successive minima occurring about every half wavelength of the carrier transmission frequency [14].

Free space is an ideal propagation model that can be accurately applied only to satellite communication and short line-of-sight radio links has a path-loss slope of 20 dB/decade. While in mobile radio environments, a path-loss slope of 40 dB/decade is always applied. In general, a mobile radio signal $r(t)$, can be characterized by two components $m(t)$, and $r_0(t)$ based in natural physical phenomena where

$$r(t) = m(t)r_0(t) \tag{2.14}$$

The component $m(t)$ is called *local mean*, also called *slow fading*, *long-term fading*, or *log-normal fading* and its variation is due to the terrain contour between the base station and the mobile unit, here the signal being blocked by a large structures or by hills and mountains. The factor r_0 is called *multipath fading* or *short-term fading*, or *Rayleigh fading* and its variation is due to the waves reflected from the surrounding buildings and other structures.

In the case of a direct wave path (a path clear from the terrain contour) or a line-of-sight path (a path clear from buildings), although the 40 dB/decade path-loss slope remains the same, the short-term fading is observed to be Rician fading. It results from a strong line-of-sight path and a ground-reflected wave combined, plus many weak building-reflected waves. When an out-of-sight condition is reached, the 40 dB/decade path-loss slope still remains as shown in Fig. 2.9. However, all reflected waves, including ground-reflected waves and building-reflected waves, become dominant. The short-term received signal at the mobile unit observes a Rayleigh fading. As shown in Fig. 2.10 Rayleigh fading is the most severe fading.

Studies have shown that the envelope of the mobile radio signal is Rayleigh distributed when measured over distances of a few tens of wavelengths, where the mean signal is sensibly constant, whereas, the phase of the received signal is uniformly distributed from 0 to 2π.

Another set of problems that arise in the mobile channel is a result of the motion of the mobile user and other moving objectives. The first is the *Doppler shift* that is dependent on the mobile speed and the carrier frequency. The Doppler shifts occupy a continuum between

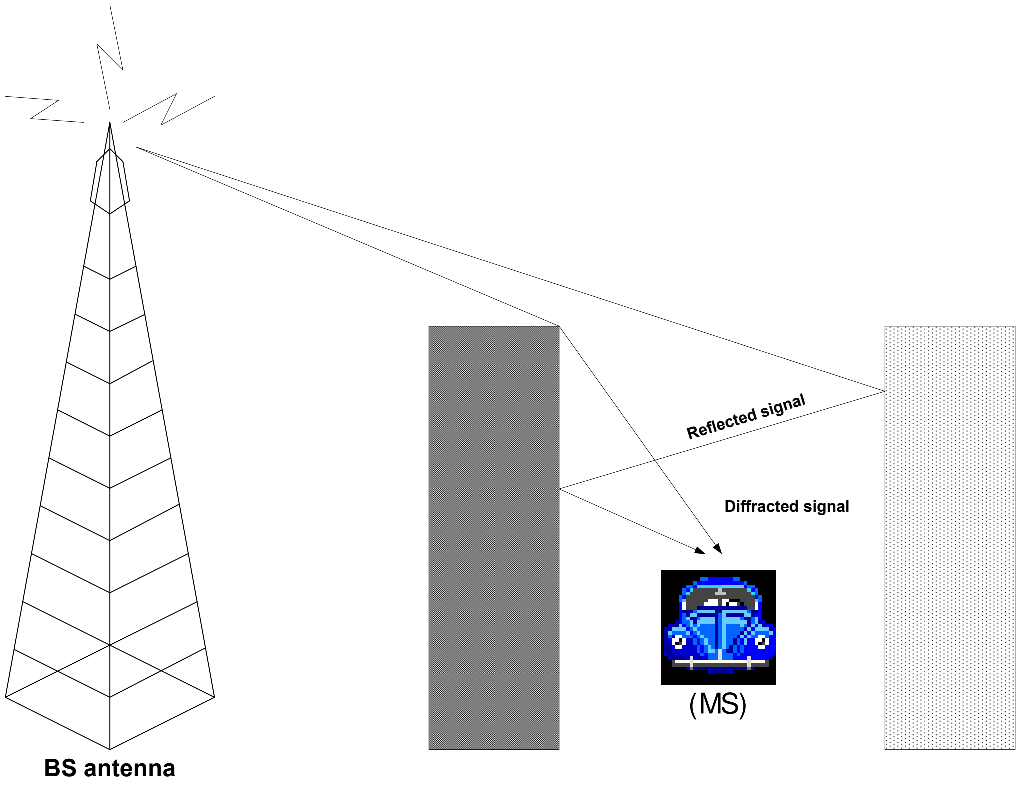


Figure 2.9: Multipath propagation in urban area.

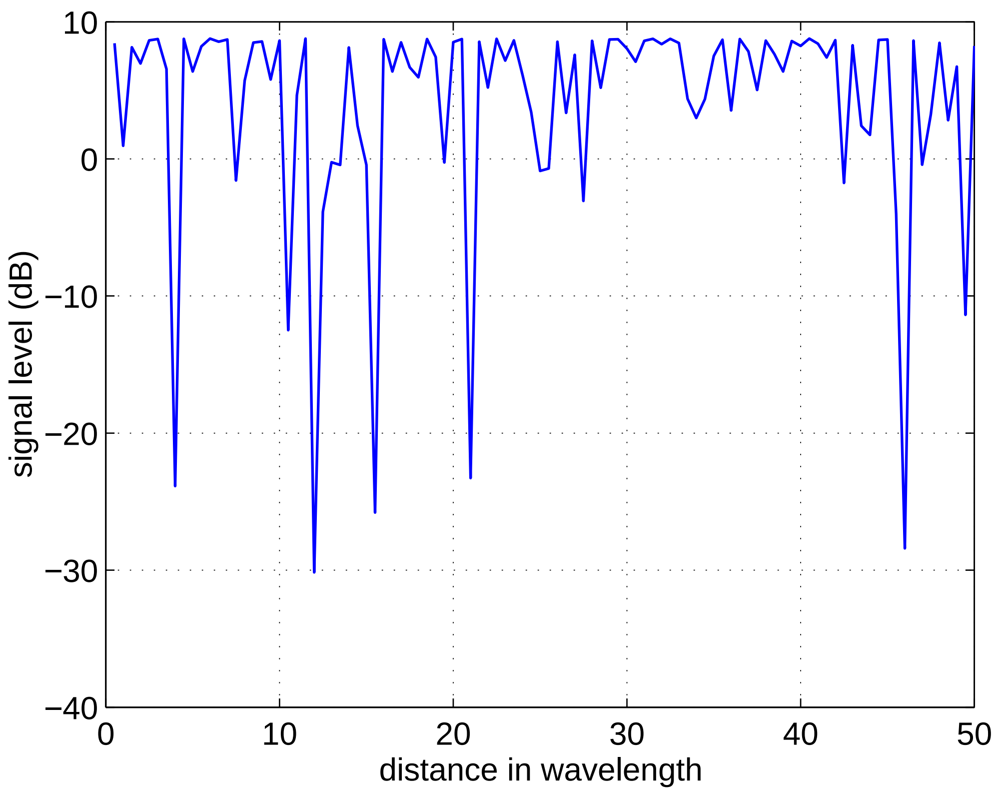


Figure 2.10: The Raleigh fading envelope

the positive and negative limits because the mobile antenna simultaneously picks up signals scattered from some objects it is moving towards and away from them. The second motion-related problem concerns cochannel and adjacent channel interference. Because of vehicle motion, a receiver and a transmitter operating on adjacent or nearly adjacent channels may be physically close together. The receiver selectivity must be extremely good to prevent substantial interference from strong transmitted signals. Also, in a cellular mobile communication system, where frequencies are reused in the same city area, cochannel interference will occur and this can not be reduced by improving receiver selectivity. Cochannel interference plays a predominant role in determining the capacity of any cellular system.

2.7 Channel Assignment Schemes

Since the frequency spectrum is the most limited resource in the cellular system, channel assignment schemes proposed so far have aimed at making efficient utilization of frequency channels [15]. With the emergence of wireless personal communications and use of microcell with non-uniform traffic, radio resource assignment becomes essential to network operation and largely determines the available spectrum efficiency. Fixed channel assignment (FCA) and dynamic channel assignment (DCA) techniques are the two extremes of allocating radio channels to mobile subscribers. For specific grade of service and quality of transmission, the assignment scheme provides a tradeoff between spectrum utilization and implementation complexity. The performance parameters from a radio resource assignment point of view are interference constraints (quality of transmission link), probability of call blocking (grade of service), and the system capacity (spectrum utilization) described by busy hour traffic that can be carried by the network. In a cellular system, however, there exist other functions, such as handoff and its execution or radio access control. These functions may be facilitated by the use of specific assignment schemes and, therefore, they should be considered in such a tradeoff.

2.7.1 Fixed channel assignment (FCA)

In fixed channel assignment the interference constraints are ensured by a frequency plan independent of the number and location of active mobiles. Each cell is then assigned a fixed number of channels, dependent on the traffic density and the cell size. These channels are permanently assigned for use in that cell. The corresponding frequency plan remains fixed on a long-term basis. For a given set of communications system parameters, the minimum allowed carrier to interference ratio $(C/I)_0$ relates to a specific quality of transmission link (e.g., probability of bit error or voice quality). This parameter in turn relates to the number of channel sets (or cluster size) given by . Thus, the frequency reuse ratio D/R is determined by $(C/I)_0$. For example, the $(C/I)_0$ of 18 dB results in $K = 7$ or the $D/R = 4.6$. Here, we have used propagation attenuation proportional to the fourth power of the distance. The radius of the cell is determined mainly by the projected traffic density. The number of channels for each cell can be determined through the Erlang-B formula by knowing the busy hour traffic and the desired probability of blocking (grade of service). Probability of blocking P_B is related to offered traffic A, and the number of channels per cell N by

$$P_B = \frac{A^N/N!}{\sum_{i=0}^{N} A^i/i!} \,. \tag{2.15}$$

This applies to the case of blocked calls cleared system. If calls are delayed, the grade of service becomes measured by the probability of calls being delayed P_D and is given by

$$P_D = \frac{\frac{A^N}{N!(1-A/N)}}{\sum_{i=0}^{N-1} A^i/i! + \frac{A^N}{N!(1-A/N)}} \tag{2.16}$$

FCA worked very well in the first generation cellular systems, which have regular cell structure and stable system configuration. With the introduction of microcells and picocells in PCS, FCA becomes inadequate because of the following:

- Frequency planning is getting more difficult and tedious in the microcellular environment since accurate propagation predictions require a more detailed knowledge of the landscape than is required for large area coverage design.

- The fixed assignment strategy does not provide the flexibility for system reconfiguration.
- FCA is not flexible enough to handle the unpredicted traffic and abnormal interference scenarios, such as traffic jam, car accident, etc.
- It is not suitable to provide "bandwidth on demand" which is important for multimedia services in PCS.

To improve the utilization while maintaining the implementation simplicity, various strategies have been proposed as enhancements to FCA and deployed in existing networks. Two often used methods are *channel borrowing* and *directed retry*.

In the channel borrowing strategy, channels that are not in use in their cells may be borrowed by adjacent cells with high offered traffic on a call-by-call basis. Borrowing of channels allows the arriving calls to be served in their own cells. This implies that there will be further restrictions in using the borrowed channels in other cells.

In directed retry, a call to or from a mobile subscriber may try other cells with channels with sufficient signal strength meeting the C/I constraint if there are no channels available in its own cell to be served. In some cases it may be necessary to direct some of the calls in progress in a given congested cell to adjacent lightly loaded cells in order to accommodate the new calls in that given cell. This is referred to as directed handoff. The combination of these two capabilities provides a significant increase in bandwidth utilization.

2.7.2 Dynamic channel assignment (DCA)

In dynamic channel assignment, the assignment of channels to cells occurs based on the traffic demand in the cells. In other words, channels are pooled together and assignments are made and modified in real time. Therefore, this assignment scheme has the potential to achieve significantly improved bandwidth utilization when there are temporal or spatial variations. In DCA, the interference constraints are ensured by a real time evaluation of the most suitable (less interfered) channels that can be activated in a given cell. That is, the system behaves as if the frequency plan was dynamically changing to meet the actual radio link quality and traffic loads, realizing an implicit sharing of the frequency band under interference constraints.

When DCA is being used, different channels are assigned to serve calls randomly. Because of this randomness, it is found that cells that have used the same frequency channel, on the average, are spaced apart at a greater distance than the minimum reuse distance. Since DCA implies the lack of a fixed relationship between cells and channels. This definition allows for almost an infinite variety of dynamic channel assignment procedures a[16]. Many studies have focused in this field are presented in [16, 17, 18, 19, 20]. For example channel reassignment methods are presented in [19] to improve the performance of DCA, where calls already in progress are switched back, whenever possible, to other fixed channels with the objective of keeping the distance between cells using the same channel simultaneously to a minimum [20]. This frees the dynamic channel for future assignment and ensures that a large number of calls is being served by the optimally spaced fixed channels [19].

The performance of DCA depends on the algorithm implementing this capability. In general, due to interactions between different cells, the performance of the system will involve modeling the system as a whole, as opposed to in FCA where cells are treated independently. Therefore, mathematical modeling and performance evaluation of DCA becomes quite complex. Simplifying assumptions may, therefore, be necessary to obtain approximate results. Simulation techniques have been widely used in evaluation of DCA performance.

2.7.3 Hybrid channel assignment (HCA)

Hybrid channel assignment technique employs a mixture of fixed and dynamic techniques. In this strategy, channels assigned to each cell are divided into two groups. The first group (nominal channels) can be used only for local calls using the FCA policy. The second group (common channels) is kept as a common pool to be shared by all subscribers on DCA basis. The common group is only used when there are no nominal channels available. By carefully adjusting the ratio of the number of channels in these two groups according to the traffic distribution it is possible to design a system to maintain good spatial efficiency and at the same time gain sufficient flexibility to respond to abnormal traffic distributions. It was found that the optimum ratio depends on the percentage increase in traffic density.

This scheme can be further improved by switching calls from the common pool to one of the nominal channels when these becomes free, this is so-called channel reassignment or intra-cell handoff previously described. It is, therefore, advantageous to carry as much of the traffic as possible on FCA. As the HCA scheme uses both FCA and DCA schemes, hence, it performs well in both heavy and light traffic conditions.

Chapter 3

Teletraffic Analysis of Mobile Radio Networks

3.1 Introduction

Teletraffic theory plays an important role in analyzing and designing the performance of information transmission systems including public switched telephone systems, mobile radio communication systems, and others [21]. The theory is intimately connected to the probability theory. A teletraffic network should be planned so that even during the periods of heaviest traffic, usually called the busy hour, the teletraffic requests attempted by users have a good chance of success. The number of communication channels to be provided for handling this traffic is normally calculated so that during the busy hour only a small, but usually predetermined proportion of calls will be blocked.

The classical teletraffic theory usually applied for public switched telephone network is extended here to take into account the mobility of users in the service area of the cellular mobile systems. If the cell is sufficiently large such that the handoff requests are negligible i.e., the probability of a MS moves out of a cell during making a call is low. In this situation the classical teletraffic theory is applicable as the method of handling the call in the fixed networks. Then mobile networks is quite similar, i.e., once the user attempted a call in a specified cell and is assigned a radio channel by its BS, he/she occupies the channel for the total call duration and when a call is over, the channel is released and could be assigned to another user. We emphasize here that in this case the channel holding time (i.e., the occupation time of the channel by the call in the cell) is equal to the call duration. This is not the case in a microcellular radio networks as we will see later.

In this chapter the classical teletraffic theory and its associated terms are discussed and analyzed to formulate the performance and determine the required parameters. Also, an extension of this classical theory to accommodate the handoff process resulting from user mobility in the microcellular structure is introduced.

3.2 Fundamentals of Teletraffic Theory

In order to get insight the detailed analysis of some basic systems, the basic terms of the teletraffic theory should be clearly defined to understand the technical differences between these systems and to be aware of which of these will suit a specified teletraffic model.

3.2.1 Basic teletraffic terms

Any queuing model is defined in terms of three characteristics, these are, the input process, the service mechanism, and the queue discipline. The input process describes the sequence of requests for service. For example, a common assumption for the input process is that of *Poisson (random) input*, where the customers are assumed to arrive according to a Poisson process. Another input process is called *quasi-random input*, where each idle source generates requests independently and with the same exponentially distributed interrequest time.

The service mechanism is the category that includes such characteristics as the number of servers (channels) and the length of time that customers hold the server. We will study models with an arbitrary number of parallel servers and with independent, identically distributed exponential service times.

The *queue discipline* specifies the disposition of blocked customers (customers who find all servers busy). We will consider three different queue service disciplines. When blocked customers do not wait, but return immediately to their prerequest state, the queue discipline is said to be *blocked customers cleared* or blocked calls cleared (BCC). When blocked customers wait as long as necessary for service, the queue discipline is said to be *blocked customers delayed* (BCD). And when customers are assumed to stay in the system for a time duration (sojourn time) that is independent of the state of the system, the queue discipline is said to be *blocked customers held* (BCH).

Based on the above definition of the queue model we can define some teletraffic terms as:

- **Call arrival rate**

The demand for telephone calls may arise randomly at any hour of the day. Although the call arrival rate varies significantly with time, the rate associated with the peak demand is the most important. Dividing the number of calls requests during a measured time interval by the interval gives the mean call rate λ.

- **Call duration**

Once a call attempt is successful and a channel is assigned, the period of time during which the channel is occupied by the user is called the *call duration* or *the channel holding time* T. Because calls occupy the channel for a random length of time, we are usually interested in the mean call duration. A most widely used distribution for the channel holding time is the negative exponential distribution (NED), given its probability density function (pdf) in Eq. (3-1), with the mean $\bar{T} = {}^1/_\mu$, where μ is called the *termination* or the *departure* rate. The most important feature of this distribution, beside its mathematical tractability, is its *memoryless* property. The memoryless property, sometimes called the *Markovian* property, means that the probability that a call terminates in a given interval does not depend on the time the call has been in progress.

$$f_T(t) = \begin{cases} \mu e^{-\mu t} & \text{for } t \geq 0 \\ 0 & \text{otherwise} \end{cases} \tag{3.1}$$

- **Offered traffic**

The ratio λ/μ is called the *offered traffic* or the *offered load* and is often denoted by A. It is a dimensionless quantity numerically equals to the mean number of arrivals that occur during the call duration. The offered traffic A is thus a measure of the demand placed on the system. The numerical values of A are expressed in units called *Erlangs* (*Erl.*), a unit named after A. K. Erlang, a Danish mathematician who pioneered much early telephone traffic theory. In the USA, offered traffic is also expressed in terms of hundred call-seconds per hour (CCS). 1 CCS is the offered traffic due to one call of 100 seconds duration, or 100 calls of 1-second duration, or any combination in between. We can deduce that an *Erlang* is equal to 36 CCS.

$$A = \lambda/\mu = \lambda T\,. \tag{3.2}$$

- **Grade of service**

When a call can not be set-up immediately because there is no free channel available, blocking or congestion is said to have occurred. The grade of service (GOS) is a numerical quantity that describes the level of service provided, and is synonymous with the probability of having a call attempt blocked.

- **Carried traffic**

Another useful quantity is the *carried traffic* (A_c) which is defined in general for systems in statistical equilibrium as the mean number of busy channels. From its name, the carried traffic reflects the proportion of calls that is handled by the system (not blocked) and thus, it is the difference between the offered traffic and the blocked or lost traffic.

3.2.2 General birth-death process

To set-up a teletraffic model with any queue discipline, we establish a general model to determine the probability of having a certain number of channels being busy. The arrival and termination of a call can be represented by birth and death processes, respectively. The number of calls (waiting and in service) in the network is represented by states $j = 0, 1, 2, \cdots$. The development of queuing models that are birth-death process, and for which the input process, the service mechanism, and the queue discipline can be specified through choice of birth rates λ_j and the death rates μ_j. We are interested in the steady state condition, which is reached under statistical equilibrium. The statistical equilibrium means that the chance of finding the network in any specified state is the same. Equivalently, the statistical equilibrium state probabilities are defined when the probability to move to state j is equal to the probability of leaving state j, i.e.,

$$\mu_j P_j = \lambda_{j-1} P_{j-1} \,. \tag{3.3}$$

By iterations,

$$P_j = \frac{\lambda_{j-1}\lambda_{j-2}\cdots\lambda_0}{\mu_j\mu_{j-1}\cdots\mu_1} P_0, \tag{3.4}$$

where the value of P_0 is obtained by setting the summation of all probabilities to unity.

3.3 Some Basic Models

In this section we are going to analyze some basic teletraffic models with different queue disciplines, the input process is assumed to be Poisson (random) or quasi-random process.

3.3.1 Erlang loss formula BCC (random traffic)

The demand for telephone calls has a random nature. Calls arrive at the network and depart at random, and the number of calls in progress, and hence the number of busy channels,

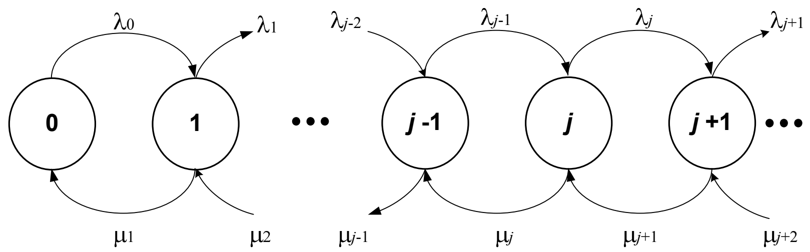


Figure 3.1: State transition diagram for general birth-death process.

will vary in a random fashion. This randomness of call arrivals implies that the inter-arrival time between calls is negatively exponential distributed. If the mean arrival rate is λ, then the mean inter-arrival time is $^1/_\lambda$. This means that calls arrive without reference to each other and independently on the state of the network. Furthermore, this randomness implies that the probability that k calls originate during an arbitrary time interval t is distributed according to the Poisson law given in Eq. (3-5)

$$P_k\left(t\right) = \frac{\left(\lambda t\right)^k}{k!} e^{-\lambda t} \,. \tag{3.5}$$

The theoretical support for this is that the number of users should be infinite. Practically this condition is satisfied when the number of users is large compared to the number of channels (e.g. by a ratio of 10). Therefore, for N channels BCC system as shown in Fig. 3.2 the call arrival rate, generated by an infinite number of users, is independent of the number of users already engaged, so we can write

$$\lambda_j = \begin{cases} \lambda & 0 \leq j \leq N-1 \\ 0 & j = N \end{cases} \,. \tag{3.6}$$

Because the call duration has a negative exponential distribution, when there are j calls in progress the departure rate μ_j is

$$\mu_j = j\mu \qquad 0 \leq j \leq N \,.$$

To obtain the probability of finding j channels being busy for BCC system with infinite number of users, we can insert Eq. (3-6) and Eq. (3-7) into Eq. (3-4), thus

$$P_j = \frac{{(^\lambda/_\mu)^j}/{j!}}{\sum_{k=0}^{N} {(^\lambda/_\mu)^k}/{k!}} \,. \tag{3.7}$$

The above distribution is called the *truncated Poisson distribution.* A most useful measure to evaluate the system performance is the GOS previously defined. Here we recall that the GOS for the BCC system is the probability of finding all channels being busy (often called

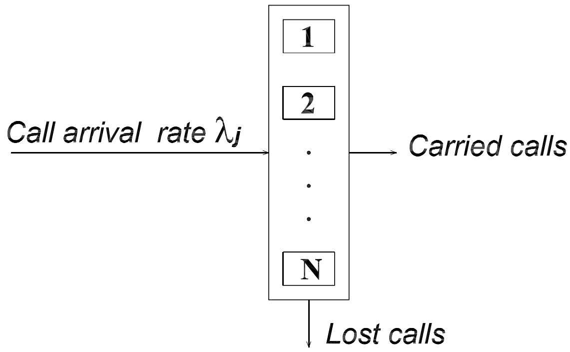


Figure 3.2: Blocked calls cleared BCC system.

the blocking probability P_B) and thus a call attempt will be lost and cleared from the system. This will be intuitively obtained by substituting $j = N$ in Eq. (3-8), therefore

$$P_B = P_N = \frac{(\lambda/\mu)^N / N!}{\sum_{k=0}^{N} (\lambda/\mu)^k / k!}\,. \tag{3.8}$$

This formula was first derived by Erlang in 1917, called the *Erlang loss formula* in the United States and is denoted by $B\,(N, A)$. While in Europe it is called *Erlang's first formula* and is denoted by $E_{1,2}\,(A)$ where $A = \lambda/\mu$ is the offered traffic previously defined. An application of the BCC assumption arises in telephone traffic engineering, where calls that find all trunks busy are given a busy signal.

3.3.2 Engset formula BCC (quasi-random traffic)

We assume that the number of users M is finite (but still greater than the number of channels N) and each user independently generates requests at rate α when idle. Clearly, the arrival call rate will not be constant (independent of the network state) as in Poisson random arrivals, but it will depend directly on the number of idle users, therefore we have

$$\lambda_j = \begin{cases} (M-j)\,\alpha & 0 \le j \le N-1 \\ 0 & j = N \end{cases}\,. \tag{3.9}$$

For the negative exponential distribution of the call duration as in Eq. (3-7) $\mu_j = j\mu$ for $0 \leq j \leq N$, substituting λ_j and μ_j into Eq. (3-4) with the offered traffic per user being $a = {}^{\alpha}/_{\mu}$, yields

$$P_j = \frac{\begin{pmatrix} M \\ j \end{pmatrix} a^j}{\sum_{k=0}^{N} \begin{pmatrix} M \\ k \end{pmatrix} a^k}. \tag{3.10}$$

To evaluate the performance of this system, we could obtain the *time congestion*, which is the probability, that all the channels are busy as

$$P_N = \frac{\begin{pmatrix} M \\ N \end{pmatrix} a^N}{\sum_{k=0}^{N} \begin{pmatrix} M \\ k \end{pmatrix} a^k}. \tag{3.11}$$

Another important measure is the *call congestion*, which is the blocking probability, does not necessitate equal to the time congestion because although all the channels may be busy, no calls may arrive during this interval. The call congestion or the blocking probability is obtained as

$$P_B = \frac{\begin{pmatrix} M-1 \\ N \end{pmatrix} a^N}{\sum_{k=0}^{N} \begin{pmatrix} M-1 \\ k \end{pmatrix} a^k}. \tag{3.12}$$

3.3.3 Erlang delay formula BCD

In the delay system, users who find all N channels busy join a queue and wait as long as necessary for service, that blocked calls delayed. In other words, no channel can be free if a user is waiting. The number of waiting positions in the queue is assumed to be infinite with service on first input first output (FIFO) basis as shown in Fig. 3.3. The input process is assumed to be Poisson (infinite number of users) and the channel holding time follow the

NED, therefore both the call arrival rate and the departure rate are given by

$$\lambda_j = \lambda \qquad j = 0, 1, 2, \cdots \tag{3.13}$$

$$\mu_j = \begin{cases} j\mu & j = 0, 1, 2, \cdots, N \\ N\mu & j = N, N+1 \cdots \end{cases} . \tag{3.14}$$

Eq. (3-15) is obtained from the assumption of NED of the channel holding time. That implies that if at any time all the j calls in the system are in service, the rate at which service completions occur is $j\mu$; if all N channels are busy, only those users that are in service are eligible to leave.

To obtain the probability of finding j channels being busy, we can insert Eq. (3-14) and Eq. (3-15) into Eq. (3-4), thus

$$P_j = \begin{cases} \frac{A^j}{j!} P_0, & j = 0, 1, \cdots, N-1 \\ \frac{A^j}{N! N^{j-N}} P_0, & j = N, N+1, \cdots \end{cases} \tag{3.15}$$

where P_0 is given by

$$P_0 = \left[\sum_{k=0}^{N-1} \frac{A^k}{k!} + \sum_{k=N}^{\infty} \frac{A^k}{N! N^{k-N}} P_0 \right]^{-1} . \tag{3.16}$$

If $A < N$, the infinite geometric sum on the right of Eq. (3-17) converges, and

$$P_0 = \left[\sum_{k=0}^{N-1} \frac{A^k}{k!} + \frac{A^N}{(N-1)!\,(N-A)} \right]^{-1} . \tag{3.17}$$

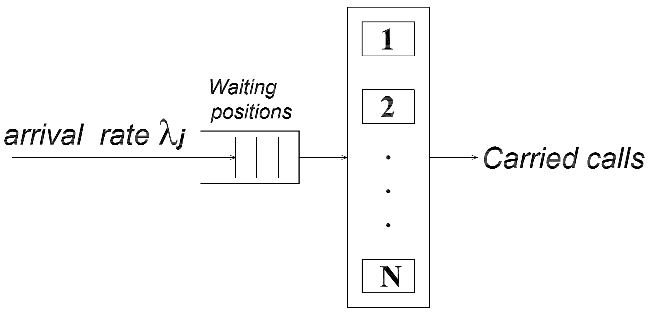


Figure 3.3: Blocked calls delayed BCD system.

If $A \geq N$, the infinite geometric sum diverges to infinity. In this case, we say that no statistical equilibrium distribution exists. The probability that all channels are occupied (and thus calls arrived in this case will forced to wait for service) i.e., the delay probability is

$$\sum_{j=N}^{\infty} P_j = \frac{A^N}{(N-1)!\,(N-A)} P_0 \qquad 0 \leq A < N,$$

which is given by the *Erlang delay formula* as

$$P_D = C\,(N, A) = \frac{A^N / [(N-1)!(N-A)]}{\sum_{k=0}^{N-1} \left(A^k / k! \right) + A^N / [(N-1)!(N-A)]} \qquad 0 \leq A < N\,. \tag{3.18}$$

Another name used in Europe for this formula is called *Erlang's second formula* and is denoted by $E_{2,N}\,(A)$.

3.3.4 The Poisson formula BCH

In the BCD model blocked users wait as long as necessary for service, and in the BCC model blocked users don't wait at all. An intermediate assumption is that an arriving user is willing to spend an amount of time T (called the *sojourn time*) in the system, where time is a random variable, after which he/she will depart regardless of whether or not at the expiration of his sojourn time he is in service or is still waiting in the queue. In other words, a blocked user will wait for service as long as time T; if he receives service before the expiration of T, he then holds the channel for the remainder of T. This queue discipline is called *blocked calls held* (BCH) as shown in Fig. 3.4.

For Poisson input process and NED call sojourn time with mean μ^{-1}, the birth-death coefficients are

$$\lambda_j = \lambda, \qquad j = 0, 1, 2, \cdots \tag{3.19}$$

$$\mu_j = j\mu, \qquad j = 0, 1, 2, \cdots \tag{3.20}$$

Substitution of Eq. (3-20) and Eq. (3-21) into Eq. (3-4) yields the familiar Poisson distribution

$$P_j = \frac{A^j}{j!} e^{-A}, \qquad j = 0, 1, 2, \cdots$$

This equation is valid for all $A \geq 0$. Note that by the Markov property the sojourn time and the channel holding time (service time) distribution functions are identical. As is now evident, the BCH state probabilities Eq. (3-22) can be viewed as the BCC state probabilities Eq. (3-8) with $N = \infty$. The probability that an arriving user will find all N channels busy is denoted by $P(N, A)$, where

$$P(N, A) = \sum_{j=N}^{\infty} \frac{A^j}{j!} e^{-A}, \qquad j = 0, 1, 2, \cdots$$

An important remark is that $B(N, A) < P(N, A) < C(N, A)$ for $A > 0$ and $N = 1, 2, \cdots$.

3.4 Teletraffic Theory for Cellular Mobile Radio

In cellular mobile radio systems, mobile telephone users cross cell boundaries while their calls are in progress, required handoff process to continue their calls by another base station. This mobility-based event has two basic effects on the traffic performance engineering of cellular mobile system that is not considered in the design of fixed systems. *First*, the call arrival rate to the system (base station in this case) is not composed of new call rate only, but include also the handoff call rate from all the neighboring cells. This handoff as we will see later is dependent on the new call arrival rate for the cell; the cell boundary crossing rates of the mobiles in the service area; and other system parameters including cell radius, average message duration, and average mobile speed. *Second*, the mean channel holding time in the cell is not necessitated to be equal to the mean call duration as explained in the following

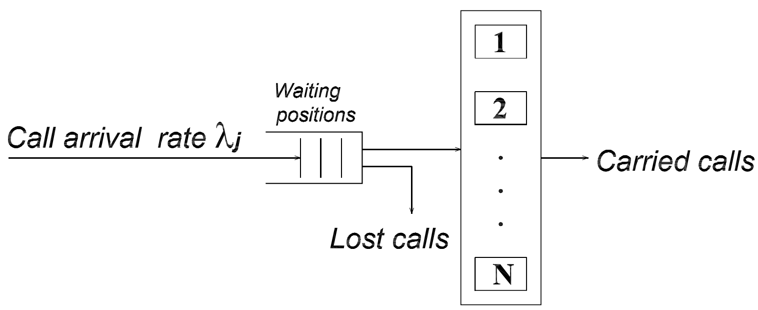


Figure 3.4: Blocked calls held BCH system.

paragraph. When a call is originated in a cell and gets a channel, the call holds the channel until the call is completed in the cell or the mobile moves out of the cell. Therefore, the channel holding time in the cell T_{Hn} is either the mean call duration T_M or the time T_n for which the mobile resides in the cell (from the onset of the call), whichever is less. For a call that has been handed off successfully, the channel is held until the call is completed in the cell or the mobile again moves out of the cell before call completion. Because of the memoryless property of the exponential distribution, the remaining duration of a call after handoff has the same distribution as the mean call duration. In this case the channel holding time in the cell T_{Hh} is either the remaining of the call duration T_M or mobile residing time T_h in the cell (from cell crossing); whichever is less. This is represented mathematically as

$$\begin{aligned} T_{Hn} &= \min\left(T_M, T_n\right) \\ T_{Hh} &= \min\left(T_M, T_h\right) \end{aligned} \tag{3.21}$$

The average channel holding time in the cell $\bar{T}_H$ will be obtained from both T_{Hn} and T_{Hh} as we will see later.

Once, the total call arrival rate (new and handoff calls) and the average channel holding time are determined for an arbitrary cell. The cellular mobile teletraffic modeling could be analyzed and evaluated to obtain the performance measures that determines the required GOS in terms of blocking probability according to the aforementioned queue disciplines models. The design is usually achieved for a mobile station-to-base station or vice versa (MS$\leftrightarrow$BS) communication path which indeed is valid for the whole system design if we consider a large number of cells, with uniformly distributed users in the whole service area. Under statistical equilibrium each cell will exhibit similar statistical behavior independently. For mobile station-to-mobile station MS$\leftrightarrow$MS communications, the case will not much differs because if the blocking probability of MS$\leftrightarrow$BS is P_B, then the successful connection of MS$\leftrightarrow$MS will be

$$P_{succ} = \left(1 - P_B\right)\left(1 - P_B\right) \ . \tag{3.22}$$

Then the blocking probability of MS↔MS connection P_{Bm-m} is

$$P_{Bm-m} = 1 - P_{succ}\,. \tag{3.23}$$

Chapter 4

Mobility Management in Multilayered Systems

4.1 Introduction

One of the important engineering issues in cellular communication systems is to improve spectrum efficiency because teletraffic demands for wireless communications services are increasing dramatically. Microcell systems can be given more channels per unit coverage area than macrocell systems so that the spectrum efficiency of microcell systems is better than that of macrocell systems. However, microcell systems are not cost effective in areas with low user population density due to base station building cost; they are also not suitable for high mobility users with large handoff rate. Therefore, cellular systems with hierarchical structure were proposed to take the advantages of both microcell and macrocell systems [22].

Serving both low- and high-mobility user populations within an integrated system represents a major challenge in PCS. To do this objective, a wireless system should strive to maximize the number of subscribers while keeping the network control (associated with handoff) at an acceptable level. Achieving the conflicting goals of maximizing network capacity (which implies the use of small cells i.e., microcells) and minimizing network control (which favors large cells i.e., macrocells), requires a system architecture consisting of two tiers of cells [23].

Several researches on two tiers systems have been extensively carried out and deployed in major city centers, these include microcell and macrocell as mentioned above and represent the terrestrial systems. However, these systems would be primarily restricted to regional service because the complete deployment of such terrestrial networks take several years due to the network infrastructures needed to cover the entire service area. As a consequence, such deployment will start in more densely populated geographical (metropolitan) areas, where the communication demand is higher. Whereas areas characterized by spread-out population and/or low communication demand (rural and developing areas) will have to wait a long time for a homogeneous distribution of the network facilities [24]. It is thus evident that a new dimension of the multilayer system should be introduced to obtain a seamless coverage using satellite systems.

The main advantages of the use of the satellite are the enlargement and a completion of the service area, the immediate deployment of the service and the availability of additional capacity; on the other hand, the satellite resources can not support the same traffic volume as a cellular terrestrial network [25]. Thus, integration of terrestrial and satellite systems is indispensable.

In this chapter, the multilayered systems with hierarchical structures including terrestrial systems represented by microcells, macrocells and satellite systems represented by spotbeam cells are integrated to attain the desired unified global mobile communication system. Also, the mobility management of this integration is introduced.

4.2 Mobility Management

Mobility management enables telecommunication networks to locate roaming terminals for call delivery and to maintain connections as the terminal is moving into a new service area. Thus, mobility management supports mobile terminals, allowing users to roam while simultaneously offering them incoming calls and supporting calls in progress.

The next-generation wireless networks will begin to implement terminal mobility, personal mobility, and service provider portability. Terminal mobility refers to the ability of the network to route calls to the mobile terminal (MT) regardless of its point of attachment to the network, while personal mobility is the ability of the users to access their personal services independent of their attachment point or terminal. Service provider portability allows the user and/or the MT to move beyond regional mobile networks. The users will be able to receive their personalized end-to-end services regardless of their current network–within the limits of the visited network's service offering. The wireless user terminals are connecting to the unified wireless network via their resident networks [26].

This freedom requires future wireless networks to incorporate and transport heterogeneous traffic over both wireless and wireline networks. This level of global mobile freedom will also require the coordination of a wide range of service providers, compatibility of backbone networks, and network operator agreements.

Mobility management handles all the issues associated with the mobility features of the next-generation wireless networks, such as location management and handoff management. It is the basis for ubiquitous, location-independent communications.

4.2.1 Location management

Location management is a two-stage process that enables the network to discover the current attachment point of the mobile user for call delivery. The first is location registration (or location update). In this stage, the mobile terminal periodically notifies the network of its new access point, allowing the network to authenticate the user and revise the user's location profile. The second stage is call delivery. Here the network is queried for the user location profile and the current position of the mobile host is found.

Current techniques for location management involve database architecture design and the transmission of signalling messages between various components of a signalling network. As the number of mobile subscribers increases, new or improved schemes are needed to support effectively a continuously increasing subscriber population. Since location management deals with database and signalling issues, many of the issues are not protocol dependent.

In ordinary wireline networks, such as telephone network, there is a fixed relationship between a terminal and its location. Changing the location of a terminal generally involves the network administration and it cannot easily be performed by a user. Incoming calls for a particular terminal are always routed to its associated location, as there is no distinction between a terminal and its location. In contrast, MT's are free to travel and thus the network access point of an MT changes as it moves around the network coverage area. As a result, the ID of an MT does not implicitly provide the location information of the MT and the call delivery process becomes more complex.

Current schemes for public land mobile network (PLMN) location management are based on a two-level data hierarchy such that two types of network location database, the home location register (HLR) and the visitor location register (VLR), are involved in tracking an MT. In general, there is an HLR for each network and a user is permanently associated with an HLR in his/her subscribed network. Information about each user, such as the types of services subscribed and location information, are stored in a user profile located at the HLR. The number of VLR's and their placements vary among networks. Each VLR stores the information of the MT's (downloaded from the HLR) visiting its associated area.

There are currently two commonly used standards for location management in the PLMN: the Electronic and telephone industry associations EIA/TIA Interim Standard 41 (IS-41) in North America and the Global System for Mobile Communications (GSM) in Europe, partition their coverage areas into a number of location areas (LA), each consisting of a group of cells. When a mobile enters an LA, it reports to the network the information about its current new location (*location update*). When an incoming call arrives, the network simultaneously pages the mobile (*terminal paging*) in all cells within the LA where the mobile currently resides. In these standards, the LA coverage is fixed for all users [27]. In general, all BS's belonging to the same LA are connected to the same MSC. The IS-41 standards for location registration and call delivery are presented here.

4.2.1.1 Location registration

The following is the ordered list of tasks that are performed during location registration as illustrated in Fig. 4.1.

1. The MT enters a new LA and transmits a location update message to the new BS.

2. The BS forwards the location update message to the MSC, which lunches a registration

query to its associated VLR.

3. The VLR updates its record on the location of the MT. If the new LA belongs to a different VLR, the new VLR determines the address of the HLR of the MT from its mobile identification number. This is achieved by a table lookup procedure called global title translation. The new VLR then sends a location registration message to the HLR. Otherwise, location registration is completed.

4. The HLR performs the required procedures to authenticate the MT and records the ID of the new serving VLR of the MT. The HLR then sends a registration acknowledgement message to the new VLR.

5. The HLR sends a registration cancellation to the old VLR.

6. The old VLR removes the record of the MT and returns a cancellation message to the HLR.

4.2.1.2 Call delivery

Two major steps are involved in call delivery: i) determining the serving VLR of the called MT and ii) locating the visiting cell of the called MT. Locating the serving VLR of the called MT involves the following as illustrated in Fig. 4.2.

1. The calling MT sends a call initiation signal to the serving MSC of the MT through a nearby BS.

2. The MSC determines the address of the HLR of the called MT by global title translation and sends a location request message to the HLR.

3. The HLR determines the serving VLR of the called MT and sends a route request message to the VLR. This VLR then forward the message to the MSC serving the MT.

4. The MSC allocates a temporary identifier called temporary local directory number (TLDN) to the MT and sends a reply to the HLR together with the TLDN.

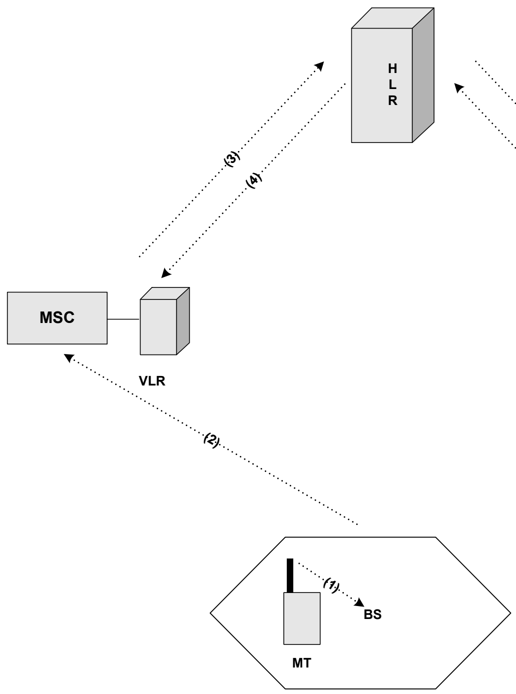


Figure 4.1: Location registration procedures.

5. The HLR forwards this information to the MSC of the calling MT.

6. The calling MSC requests a call set up to the called MSC through the signalling system 7 (SS7) network.

The procedure described above allows the network to set up a connection from the calling MT to the serving MSC of the called MT. Since each MSC is associated with an LA and there are more than one cell in each LA, a mechanism is therefore necessary to determine the cell location of the called MT. This is achieved by paging (or alerting) procedures such that polling signals are broadcast to all cells within the residing LA of the called MT. On receiving the polling signal, the MT sends a replay, which allows the MSC to determine its current residing cell.

The above procedures for location registration and call delivery result in a significant signalling traffic especially when the number of mobile subscribers keeps increasing. That is due to the centralized database architecture used. A consequence of this is that the connection set up delay may become very high. On the other hand, an advantage of the centralized

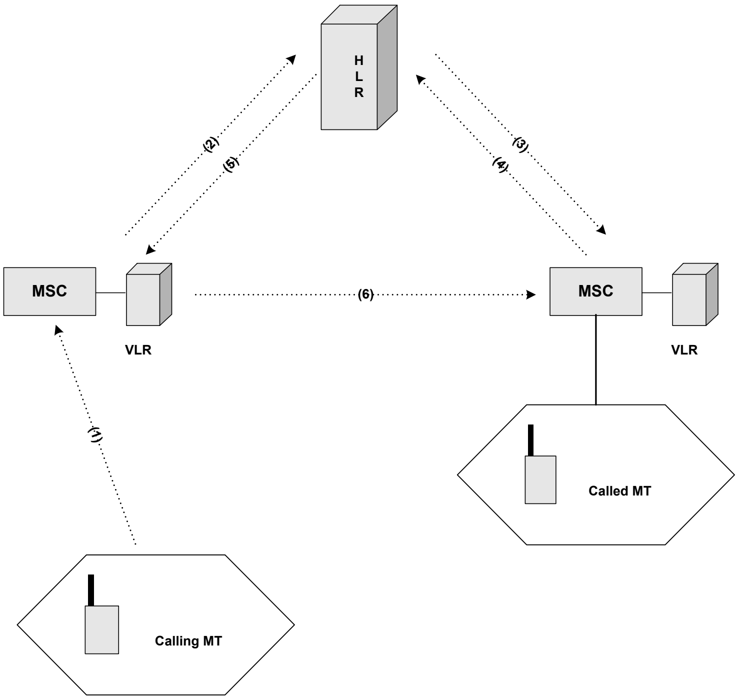


Figure 4.2: Call delivery procedures.

approach is that the number of database updates and queries for location registration and call delivery is relatively small. This minimizes the delay due to database accesses.

The distributed database approach has the advantage that database accesses are localized. An update or query to a far away database is executed only when necessary. However, the number of database accesses required for location registration and call delivery is significantly increased from that of the centralized approach. According to the aforementioned, it is likely that the ideal architecture should lie between the centralized and the fully distributed approach. Thus future research in location registration and call delivery should focus on the design of network architectures that combine, to a certain degree, the centralized and the fully distributed approaches. In addition, methods for determining the mobility level and the call arrival statistics for an MT in real-time must be developed. Dynamic schemes for limiting or enhancing the distribution of location information on a per-user basis should be considered.

4.2.2 Handoff management

Handoff is another important function of mobility management. It is unique in cellular systems and crucial to support global roaming in PCS. Handoff denotes the process of changing the channel associated with the current connection to maintain acceptable service quality or to provide better service. It is often initiated either by cell boundary crossing or deteriorated service quality in the current channel.

With the penetration of PCS, the microcell and the hybrid cell (macro-, micro-, and pico-) structure are exploited to support the drastically increased demand. The smaller cell size and the variable propagation conditions in microcells introduce much more frequent handoffs than ever before. Poorly designed handoff strategy will generate very heavy signalling traffic and worsen service quality.

To maintain acceptable service to the moving user, basic requirements for integrated systems handoff operations are the execution speed and reliability as well as transparency to the user. In addition, due to the multiple types of services supported, the handoff strategy needs to take different features of these services into account, i.e.; the ideal handoff process is service-independent. For example, voice transmission is very sensitive to interruption. On the other hand, loss data has little impact on the data performance since it can be recovered by the retransmission procedure. Therefore, a successful handoff is very important to voice, but not as critical to data (the data here is not delay-sensitive) [3].

In order to enable the seamless integration between existing and future networks, it is necessary to develop radio independent signalling protocol. In an integrated UMTS environment, a dual-mode space/terrestrial terminal will enable the continuation of an ongoing call, which otherwise would have been dropped (resulting in the subsequent degradation in quality of service), by transferring the call from one network (whether a terrestrial or satellite) to the other (satellite or terrestrial). This is known as intersegment handoff (ISHO) or vertical handoff (as the call upwards or downwards between layers). Of course the handoff between cells within the same layer (horizontal handoff) is also considered.

The priority level of the satellite resources has two criteria: i) Satellite and terrestrial resources have the same priority, and the choice between them is based on the link quality criterion. ii) Satellite resources are considered more precious than the terrestrial ones and chosen only if terrestrial resources are not available for whatever reason (e.g. lack of coverage, congestion of channels, etc.)

They represent a link-based and a network-based criterion, respectively. It is found that a more efficient resource management of the integrated system is obtained by the latter. Therefore, this criterion has been selected [24]. Thus, it is intuitively noted that horizontal handoff is the first choice, when both horizontal and vertical handoffs are available. This is due to the less impact on the system signalling traffic and design complexity encountered with the horizontal handoff. In order to implement ISHO, an effective protocol must be implemented, taking into account the difference between the propagation delays and radio interface characteristics of the respective segments (satellite and terrestrial). For maximum network efficiency, such a protocol should aim to minimize the signalling load and the signalling delay [28].

The handoff process usually consists of three phases: i) the initiation phase, ii) the decision phase, and iii) the execution phase.

The handoff may be initiated under three situations:

1. When the received signal strength degrades due to bad propagation conditions.

2. When the user moves across the cell boundary.

3. When the system needs to rearrange the resource allocation to accommodate new services.

The monitoring of the signal quality and the subsequent decision to initiate handoff encompasses the first two phases. These two phases can be performed by four different *handoff-controlling schemes*, depending on whether the MT or the network makes the decision and monitors the link quality, namely

- Network-controlled handoff (NCHO)

- Mobile-controlled handoff (MCHO)

- Network-assisted handoff (NAHO)

- Mobile assisted handoff (MAHO)

In MAHO, both mobile and network monitor the link quality. The MT monitor the current link quality of the surrounding terrestrial cells and visible satellite beams (spotbeams) and passes this information to the fixed part of the network for further analysis. The network decides when to initiate handoff and the appropriate target cell or beam to handoff the call. This scheme requires less-sophisticated MT when compared with NAHO. Furthermore, under the MAHO scheme, the handoff decision is more reliable when compared with the MCHO or the NCHO. Hence this handoff scheme has the advantages of being simple to implement and reducing the signalling load and thus was employed in the GSM mobile standard.

There are two types of handoff processes to achieve different goals, namely, *intercell handoff* and *intracell handoff*. In an intracell handoff, the user is transferred to a new channel from the current one, but the service is still provided by the same BS. This kind of handoff is usually caused by deteriorated channel quality or resource rearrangement. An intercell handoff is triggered when the user moves away from the current serving BS or the current BS cannot provide sufficient service quality.

Once the handoff initiation and decision phases have been accomplished, the handoff execution phase will follow to establish new connections with the target BS (in the terrestrial case) or the fixed earth station (FES) (in the satellite case) and to disconnect the original connections (signalling and traffic channels) with the serving BS (or FES). This requires a signalling procedure for a *handoff connection establishment* to be performed between the MT and network. There are two distinct connection establishment schemes for this signalling procedure, namely, *forward* and *backward*. The main difference between these two schemes depends on which signalling channel is used to perform the signalling exchange required for the handoff execution. The forward scheme establishes and uses a new signalling channel with the target BS (or FES) while the latter retains the old signalling link to perform signalling exchanges.

Finally, three different *transference schemes* can be used in the establishment of new traffic channels, namely, *hard handoff*, *soft handoff*, and *signalling diversity*. In the first scheme, the current traffic channel is released before the establishment of the new one, while in the second and third schemes, the current traffic connection will not be released until the new one is firmly established. In the second strategy, both the current and new traffic links are used simultaneously during handoff execution. With signalling diversity, the signalling procedures are performed through both the old and new signalling link simultaneously, while the user traffic uses the old traffic link. When the new traffic channel is firmly established, the user traffic is then switched to the new link and the old one is released [28].

Incomplete calls are considered less desirable from the user's viewpoint than the occurrence of blocking of a new call and they should be at a minimum. Since a customer's satisfaction is determined by rate of call completions and how low the connection delays are, it is the interest of the service provider to meet these satisfaction measures as much as possible [29]. Therefore, the resource assignment should give priority to handoff calls. In the following some different proposed types of priority disciplines are considered.

- **Reserved channel scheme**

In this scheme, a few channels, say N are reserved and dedicated for handoff use. Suppose there are C channels in a cell, the other $(C - N)$ channels can be shared between handoff calls and new calls. If the number of free channels is less than or equal to N, the new call will be blocked. The handoff calls can still gain access to the system until there is no available channel. This method reduces the failure rate of handoff calls at the expense of increasing the new call blocking rate and reducing the spectrum efficiency.

- **N-times retry scheme**

The unsuccessful handoff requests can be resubmitted for a specific number of times at predetermined time intervals. More retries give the handoff calls more opportunity to access the channel than the new ones. Therefore, the handoff failure rate will be reduced. The new call blocking rate remains almost unchanged since all channels are available for the new calls.

- **Queueing scheme**

The handoff call can be queued if no channel is available when the request is presented. This scheme exploits the fact that the user will spend some time in the handoff area, i.e., in this area, the user can still receive acceptable service through the old connection before the new one is established. There are two types of priority schemes, the FIFO scheme and the measurement-based priority scheme. In the FIFO scheme, the handoff request is queued according to the request arrival time. While the measurement-based priority scheme ensures that the user in the most urgent situation gets access to the system first. The problem of this priority scheme is that it is complicated compared to the FIFO one.

- **Sub-rating scheme**

Sub-rating means an occupied full-rate channel is temporarily divided into two channels at half the original rate: one to serve the existing call and the other to serve the handoff request [30]. When there is a free channel, one of the half-rate calls will be moved there, freeing up a half-rate channel which will be merged with the other half-rate one to provide a full-rate service again. This scheme trades the service quality with the system capacity [3].

4.3 Location Registration and Call Delivery Research

The cost of mobility management is defined as the sum of a mobile's location update cost and the cost incurred in paging the mobile [27]. These costs are highly dependent on the database network architecture and the signalling traffic cost associated with location update and paging.

A very large number of mobile terminals, worldwide service area, and a broad range of terminal mobilities may result in excessive supervisory signalling traffic for location updating and paging. Larger LA's allow less frequent LA boundary crossings and thus less signalling traffic for location updates. However, larger LA's imply larger paging areas, which in turn introduce, for an incoming call, longer paging delay and/or more paging traffic on control channels. The size of the LA must balance the signalling costs of location updating and paging [31]. Methods for reducing the signalling traffic are therefore needed.

Research in this area generally falls into two categories. A *centralised database* structure, which records all movements of MT's in a central database, has a simple algorithm to locate MT's. But its implementation is impractical because the centralized database cannot support such a large number of MT's in a global system. The other category is a *distributed database* structure. This structure was studied for third-generation mobile systems and consists of distributed HLR's which store the permanent MT information within any network and VLR in charge of roaming MT's in one or more location areas [32].

A study presented in [32] shows that the cost of signalling network traffic and its travelling distance is less important relative to the number database accesses and complexity of database processing for locating a MT unless the signalling network traffic exceeds certain limits, on the order of several Mb/s. This is due to the advances in fiber optic technology and the wavelength division multiplexing techniques which make it possible for transport transmission systems to have enough bandwidth up to 100 Gb/s.

4.3.1 Centralized database structure

An advantage of the centralized approach is that the number of database updates and queries for location registration and call delivery is relatively small. This minimizes the delay due to database accesses. But as the number of MT's increases, the signalling traffic may significantly degrade the performance of the network. One undesirable consequence is that the connection set-up delay may become very high.

4.3.1.1 Pointer forwarding

The basic idea of the pointer forwarding scheme is that instead of reporting a local change to the HLR every time the MT moves to an area belonging to a different VLR, the reporting can be eliminated by simply setting up a forwarding pointer from the old VLR to the new VLR. When a call for the MT is initiated, the network locates the MT by first determining the VLR at the beginning of the pointer chain and then following the pointers to the current serving VLR of the MT. To minimize the delay in locating an MT, the length of the pointer chain is limited to a predefined maximum value K. When the length of the pointer chain reaches K, additional forwarding is not allowed and location change must be reported to the HLR as shown in Fig 4.3 for $K = 2$. And then the original pointers are deleted and the HLR records the ID of the current serving VLR of the MT.

4.3.1.2 Local anchoring

Under this scheme, a VLR close to the MT is selected as its local anchor. Instead of transmitting registration messages to the HLR. Location changes are reported to the local anchor. Since the local anchor is close to the MT, the signalling cost incurred in location registration is reduced. The HLR keeps a pointer to the local anchor. When an incoming call arrives, the HLR queries the local anchor of the called MT which, in turn, queries the serving VLR to obtain a routable address to the called MT.

4.3.2 Distributed database structure

The distributed database approach has the advantage that database accesses are localized. An update or query to a far away database is executed only when necessary. However, the number of database accesses required for location registration and call delivery is significantly increased from that of the centralized approach. Careful design is needed to ensure that database accesses will not significantly increase the signalling delay.

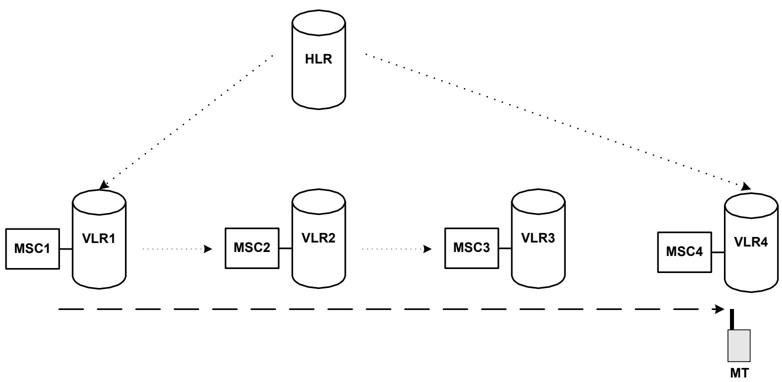


Figure 4.3: Pointer forwarding scheme.

4.3.2.1 A fully distributed database scheme

In this scheme the location databases are organized as a tree with the root at the top and the leaves at the bottom. Each location database contains location information of the MT's that are residing in its subtree. Fig. 4.4 demonstrates the operation of this scheme as shown an MT1 is located at LA1 has an entry in each database along the path from its current location to the root of the tree. When a call is initiated, the network locates the called MT by following its database entries. For example, if a call for MT1 is initiated by MT2 as shown. The call request is received by the node A. since the database of node A does not have an entry for MT1, the call request is forwarded to node B and so on. When the request finally reaches node D, an entry for MT1 is found and the location of MT1 is determined as demonstrated. It is noted that this scheme reduces the distance traveled by signalling messages. However, this scheme increases the number of database updates and queries and thus increases the delay.

4.3.2.2 Partitioning

Since the mobility pattern of the MT's varies among locations, partitions can be generated by grouping location servers among which the MT moves frequently as shown in Fig. 4.5. Based on this scheme, location registration performed only when the MT enters a partition. When an MT moves into partition P2, location server LS2 is updated indicating that the MT is residing in its subtree. No location registration is performed when the MT moves to another location server within the same partition. This scheme minimizes the number of

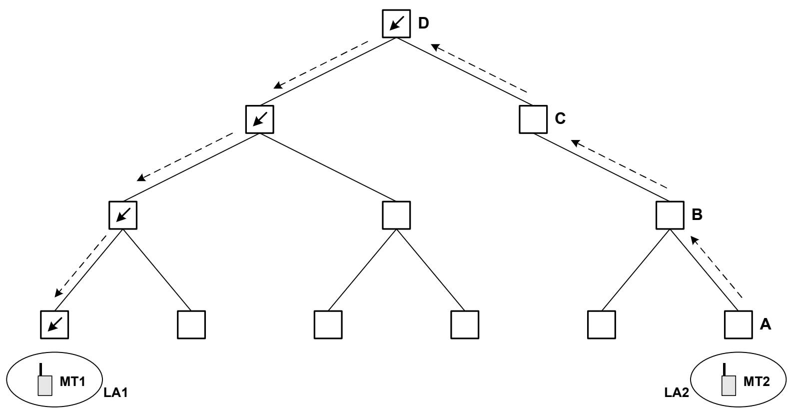


Figure 4.4: Distributed hierarchical tree database.

location registration in areas where the mobility rate of the MT's is high.

The concept of LA used in the current PLMN has a number of inefficiencies associated with the static location updates and paging of this concept as follows:

1. Excessive location updates may be performed by MT's that are located around LA boundaries and are making frequent movements back and forth between two LA's.

2. Requiring the network to poll all cells within the LA each time a call arrives may result in excessive volume of wireless broadcast traffic.

3. The mobility and call arrival patterns of MT's vary, and it is generally difficult to select an LA size that is optimal for all users. An ideal location update and paging mechanism should be able to adjust on a per-user basis.

Recent research efforts attempt to reduce the effects of these inefficiencies. Many recent efforts focus primarily on dynamic location update mechanisms, which perform location update based on the mobility of the MT's and the frequency of incoming calls (call arrival pattern) [26].

Dynamic location management schemes discard the notation of LA borders. A mobile in these schemes updates its location based on either elapsed time (*time-based*), number of crossed cell borders (*movement-based*), or traveled distance (*distance-based*). All these patterns can be dynamically adapted to each mobile's traffic and mobility patterns, hence providing better cost-effectiveness than the LA scheme [27].

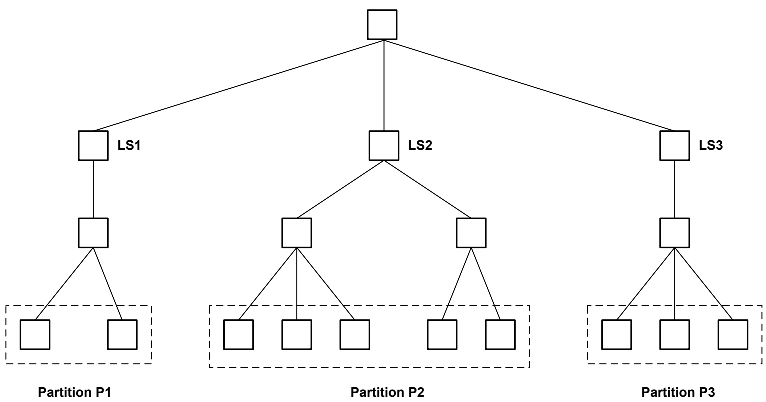


Figure 4.5: Partitioning scheme.

In the time-based scheme, the MT performs location updates periodically at a constant time interval ΔT. While in the movement-based scheme, the MT performs location update whenever it completes a predefined number of movements across cell boundaries. In the distance-based scheme, the MT performs location updates when its distance from the cell it preformed the last location update exceeds a predefined value. Researches in this area result in that the distance-based scheme produces the best performance but its implementation incurs the highest overhead.

From the preceding discussion of the location management in the future PLMN it is concluded that:

- The network design architectures should combine, to a certain degree, the centralized and the fully distributed approaches. In addition, methods for determining the mobility level and the call arrival statistics for an MT in real-time must be developed.
- The design of dynamic location update and paging schemes should be simple to implement.

Chapter 5

Teletraffic Modeling of an Integrated Space/Terrestrial Cellular Architecture with Different Priority Schemes

5.1 Introduction

The integration between terrestrial networks and satellite systems is vital for global communication. Without satellite participation, terrestrial systems would be restricted to regional service [4]. It is thus evident that integration of satellite network and terrestrial system is indispensable in order to have seamless radio coverage with sufficient capacity to accommodate anticipated high teletraffic demand. Some basic problems of handoff, different handoff scenarios, and relevant signalling aspects have been considered when GSM and MSS are integrated in the same communication system. A substantial evolution of the GSM mobility management techniques is required when integration with MSS using a dynamic satellite constellation is considered. The complete integration of a satellite network with a terrestrial cellular network is a system architecture challenge that requires solving problems at both the transmission and the network levels [24].

The hierarchical cellular structure provides an efficient way for handling different teletraffic densities. On the terrestrial segment, the microcell layer provides services for areas with high traffic densities, followed by an overlaying macrocell layer that serves moderate traffic demand and provides relief channels for clusters of microcells. On the space segment, low earth orbit (LEO) satellites introduce a new dimension to terrestrial communication for seamless global coverage and relief the high teletraffic demand rejected by the terrestrial segment. A pattern of overlapping spotbeams overlays clusters of macrocells. A general frame work for hierarchical systems with two layers based on speed sensitive are presented in [33] and [34]. In [35] terrestrial and satellite systems are integrated and different overflow strategies are introduced. A three layered integrated system with reserved channel scheme (RCS) handoff priority appeared in [36].

Many strategies have been recently proposed to privilege the handoff services at the expenses of new call arrivals. On the basis of International Telecommunication Union (ITU) requirements for land mobile services, the values of call dropping probability (P_{drop}) and call blocking probability (P_B) should not exceed 5×10^{-4} and 10^{-2}, respectively [37].

In our work a multiple hierarchical cellular communication system with different handoff priority schemes is evaluated. These include RCS, sub-rating scheme (SRS), and queueing priority scheme (QPS).

5.2 Teletraffic Modelling of Voice Communications

In this section, a proposed model for voice services is introduced. A detailed analysis is discussed in order to evaluate the performance measures of the proposed voice model.

5.2.1 Model description

Fig. 5.1 shows the encountered model layers. It is considered that every C_m microcells are overlaid by a macrocell, and every C_M macrocells are in turn overlaid by a spotbeam cell. Independent statistical behaviour between neighbouring cells is assumed. We therefore, can focus on only one cell in each layer. The operation scenario can be described with the aid of

Fig. 5.2 and the flow charts of Fig. 5.3, Fig. 5.4, and Fig. 5.5 as follows:

1. Consider that the number of channels assigned for each microcell, macrocell and spotbeam cell are N_m, N_M and N_s, respectively.

2. Consider also that the number of channels for handoff requests in each microcell, macrocell and spotbeam cell are N_{mh}, N_{Mh} and N_{sh} respectively.

3. Furthermore, N_{Mo} channels per macrocell and N_{so} channels per spotbeam cell are privileged to accommodate the handoff traffic overflowed to the macrocell and the spotbeam cell, respectively.

4. Three categories of users are existing in the system. These are terrestrial-only users with access to terrestrial subnetwork, satellite-only users with access to the space segment only and dual-mode users with access to both terrestrial and space segments.

5. A call attempt in terrestrial network is directed first to the lowest layer, i.e., the microcell. The call is served if the number of channels in use is less than $N_m - N_{mh}$, or overflowed to the umbrella macrocell and gets service there if the number of channels in use is less than $N_M - N_{Mo} - N_{Mh}$. Otherwise, the call is directed to the overlaid highest layer (spotbeam cell) and served there if the number of channels in use in the spotbeam cell is less than $N_s - N_{so} - N_{sh}$.

6. Handoff requests are privileged with more reserved channels. A handoff request is served in the microcell if the number of channels in use are less than N_m and in the macrocell if the number of channels in use are less than $N_M - N_{Mh}$, and in spotbeam cell if the number of channels in use are less than $N_s - N_{sh}$.

A similar approach is adopted for new and handoff calls initiated firstly in macrocells. In addition to reserved channel scheme, channel sub-rating is also applied. For those calls first initiated in the spotbeam cell we, furthermore, implement a queueing priority scheme in this layer.

Note that since the direction of handoff overflow is upward only in the system hierarchy (i.e., handoff requests search for idle channels starting from the same hierarchical level), and

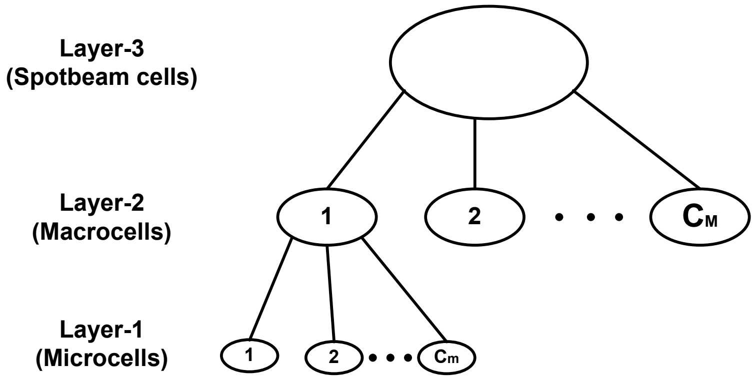


Figure 5.1: Hierarchical multilayer architecture.

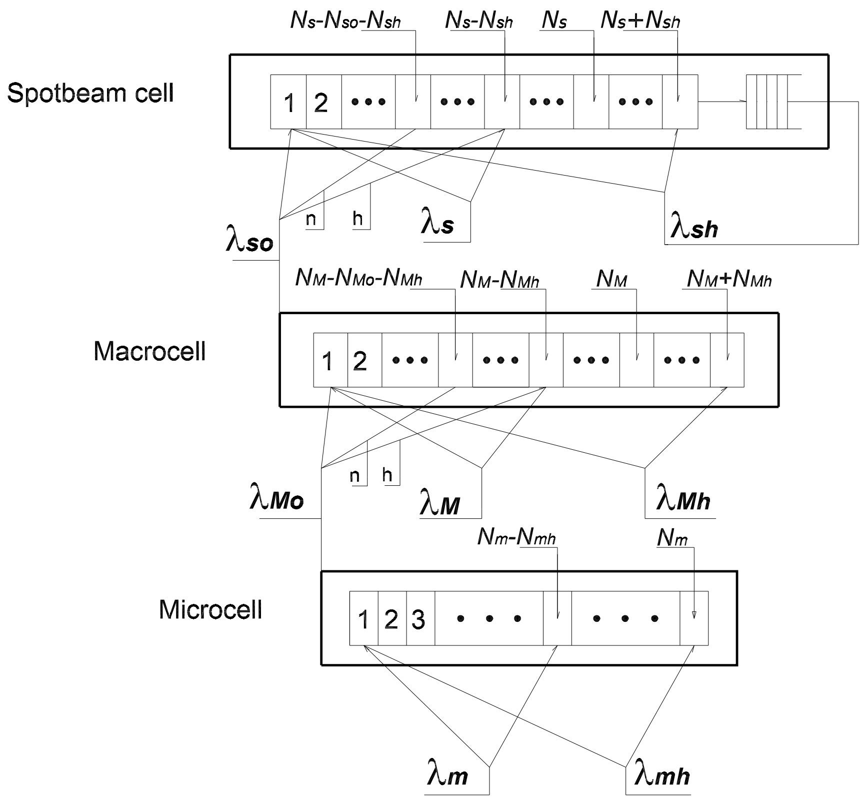


Figure 5.2: Channel allocation for new and handoff calls in each layer.

a call will not revert to service at lower level, the system operation tends to create a traffic distribution in which high mobility users are more likely to be served by the larger cells (i.e., cells that are higher in system hierarchy). This traffic distribution is achieved without any other mechanism for mobility management, such as those based on speed measurements for initial cell assignment [36].

5.2.2 Performance analysis

In this section, a comprehensive analysis of the system performance in each level of the hierarchy is introduced to obtain the performance measures of the system. These include new call blocking, handoff failure, forced termination, and noncompletion probabilities.

- **Microcell level**

A hexagonal microcell shape with radius R_m is considered. A large population of mobile users is assumed so that the average new call rate is independent of the number of calls in progress. Each microcell is allocated N_m channel with fixed channel allocation (FCA) scheme. Out of those channels, N_{mh} is exclusively reserved for handoff requests. The new call rate in each microcell λ_m is related to the microcell radius, R_m, average user density in the microcell, D_{um}, and new call rate per user λ_u as

$$\lambda_m = \frac{3\sqrt{3}}{2} R_m^2 \lambda_u D_{um} \,. \tag{5.1}$$

The channel holding times of new calls T_{Hn1}, and handoff calls T_{Hh1}, in the microcell are given by [38, 39]

$$\begin{aligned} T_{Hn1} &= \min\left(T_M, T_{n1}\right), \\ T_{Hh1} &= \min\left(T_M, T_{h1}\right), \end{aligned} \tag{5.2}$$

where T_M is the average call duration, T_{n1} is the residing time of a call initiated in the microcell. The time T_{h1} is the residing time of a handoff call in the microcell. Assume that T_M, T_{n1}, and T_{h1} are independent negatively exponentially distributed random variables with mean values of $\bar{T}_M = {}^1\!/\!_{\mu_M}$, $\bar{T}_{n1} = {}^1\!/\!_{\mu_{n1}}$, and $\bar{T}_{h1} = {}^1\!/\!_{\mu_{h1}}$ respectively. Let P_{Bm}, and P_{fhm} denote the blocking and handoff failure probabilities at the microcell layer, respectively. The

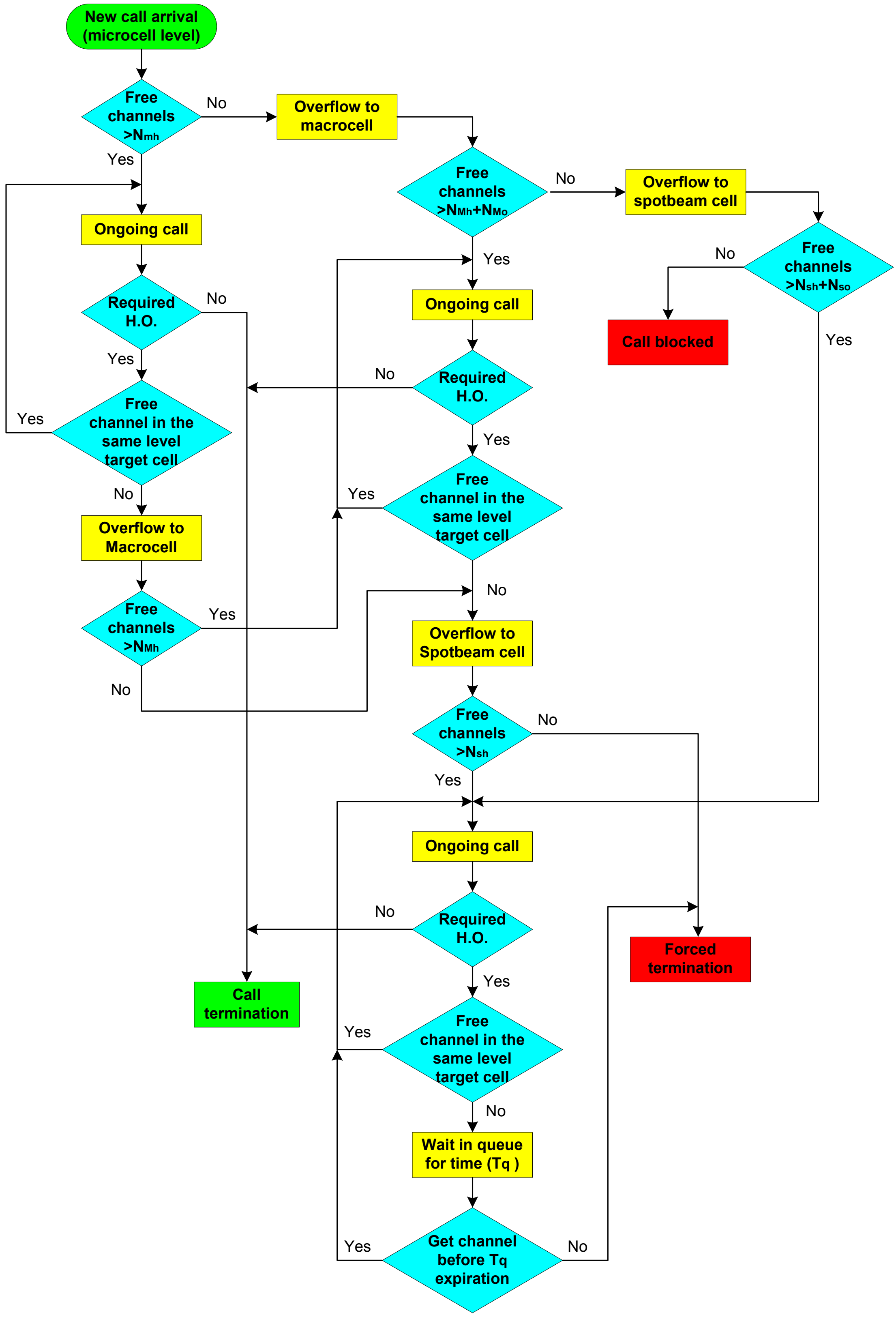


Figure 5.3: Flow chart for a call initiated in the microcell layer.

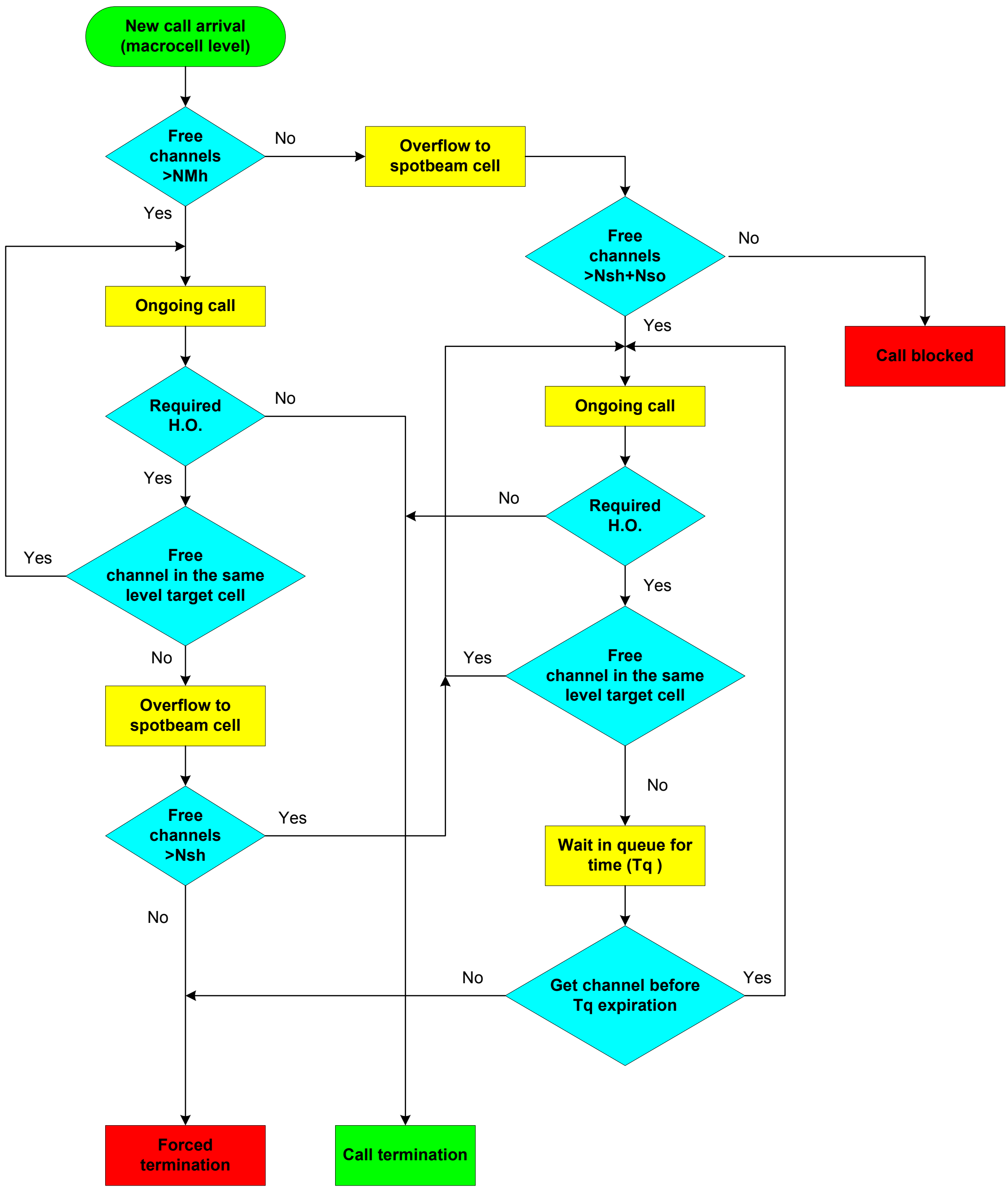


Figure 5.4: Flow chart for a call initiated in the macrocell layer.

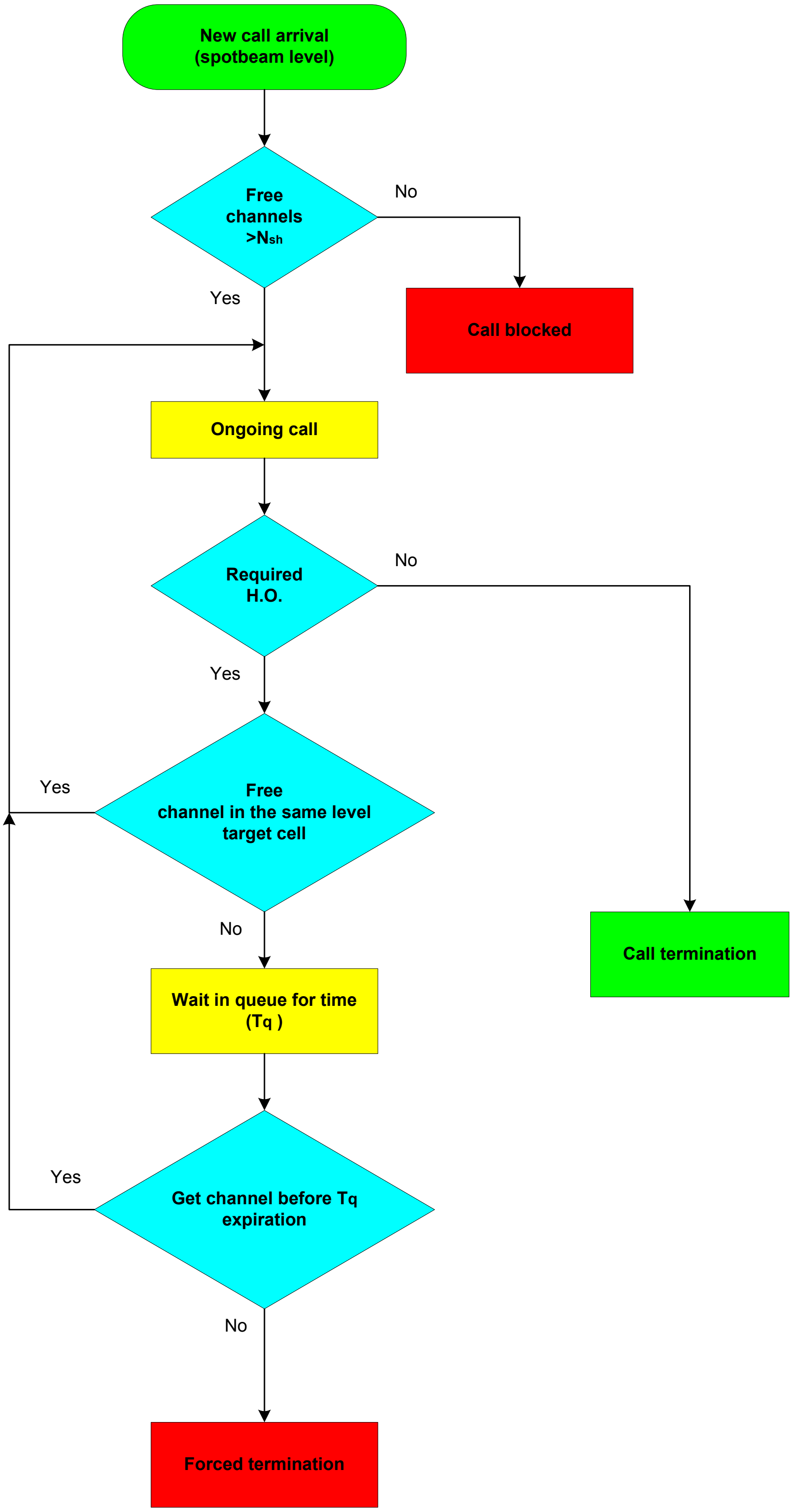


Figure 5.5: Flow chart for a call initiated in the spotbeam cell layer.

average channel holding time $\bar{T}_{H1} = {}^{1}\!/_{\mu_{H1}}$ of all calls handled by BS can be obtained as

$$\bar{T}_{H1} = \frac{\left[\frac{\lambda_m(1-P_{Bm})}{\mu_M+\mu_{n1}} + \frac{\lambda_{mh}\left(1-P_{fhm}\right)}{\mu_M+\mu_{h1}}\right]}{\lambda_m\left(1-P_{Bm}\right)+\lambda_{mh}\left(1-P_{fhm}\right)}\,. \tag{5.3}$$

The probability that a successfully initiated call requires handoff is

$$P_{N1} = \mu_{n1}\left(\mu_{n1}+\mu_M\right)^{-1}, \tag{5.4}$$

while the probability that a handoff call will require more handoff is given by

$$P_{H1} = \mu_{h1}\left(\mu_{h1}+\mu_M\right)^{-1}\,. \tag{5.5}$$

The handoff call rate can be obtained as

$$\begin{aligned} \lambda_{mh} &= \lambda_m\left(1-P_{Bm}\right)P_{N1} + \lambda_m\left(1-P_{Bm}\right)P_{N1}\left(1-P_{fhm}\right)P_{H1} + \cdots \\ &= \frac{\lambda_m\left(1-P_{Bm}\right)P_{N1}}{1-\left(1-P_{fhm}\right)P_{H1}}\,. \end{aligned} \tag{5.6}$$

The state transition diagram of the microcell BS is shown in Fig. 5.6. The steady state probability, P_j, can be determined as

$$P_j = \begin{cases} \frac{(\lambda_m+\lambda_{mh})^j}{j!\mu_{H1}^j}P_0, \\ \qquad 1 \le j \le N_m - N_{mh} \\ \frac{(\lambda_m+\lambda_{mh})^{N_m-N_{mh}}\lambda_{mh}^{j-(N_m-N_{mh})}}{j!\mu_{H1}^j}P_0, \\ \qquad N_m - N_{mh} + 1 \le j \le N_m \end{cases} \tag{5.7}$$

where

$$\begin{aligned} P_0^{-1} &= \sum_{k=0}^{N_m-N_{mh}} \frac{(\lambda_m+\lambda_{mh})^k}{k!\mu_{H1}^k} \\ &\quad + \sum_{k=N_m-N_{mh}+1}^{N_m} \frac{(\lambda_m+\lambda_{mh})^{N_m-N_{mh}}\lambda_{mh}^{k-(N_m-N_{mh})}}{k!\mu_{H1}^k}\,. \end{aligned} \tag{5.8}$$

The blocking probability of new calls, P_{Bm}, and handoff failure probability, P_{fhm}, are given by

$$P_{Bm} = \sum_{j=N_m-N_{mh}}^{N_m} P_j, \tag{5.9}$$

$$P_{fhm} = P_{N_m}\,. \tag{5.10}$$

The overflow rates of new and handoff calls directed to the next layer (i.e., macrocell) are, respectively, given by

$$\lambda_{Mon} = \lambda_m P_{Bm} C_m, \tag{5.11}$$

$$\lambda_{Moh} = \lambda_{mh} P_{fhm} C_m\,. \tag{5.12}$$

Then the total overflow rate to the macrocell is

$$\lambda_{Mo} = \lambda_{Mon} + \lambda_{Moh}\,. \tag{5.13}$$

The work reviewed seems to indicate that when analyzing a hierarchical system, problems lie mostly with the modelling of the overflow traffic, which is definitely not Poisson, and with the introduction of a handoff facility at the upper level of the hierarchy [35]. We approximate the overflow traffic by a Poisson process. Although Markov-modulated Poisson process (MMPP) is more accurate for modelling the overflow traffic, it is concluded in [40] that the result obtained from modelling the overflow traffic by Poisson process and MMPP

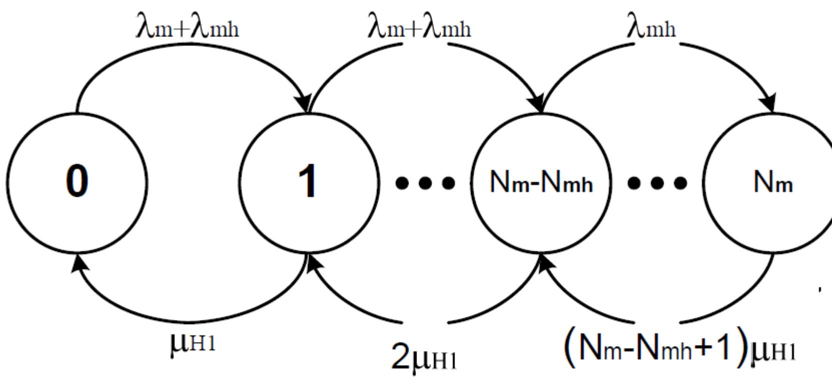


Figure 5.6: State transition diagram for microcell.

are very close. So, for simplicity we choose to consider Poisson modelling.

- **Macrocell level**

The macrocell BS handles both traffic belonging to this level (i.e., new and handoff calls placed in regions uncovered by microcells) as well as the overflowed traffic denied in those microcells underlayed the macrocell. Each macrocell is allocated N_M channels, from which N_{Mo} can not be accessed by new calls overflowed from microcells but allowed for the new calls initiated in the macrocell and the overflow handoff attempts. Also N_{Mh} channels are reserved for handoff calls in this level as shown in Fig. 5.2. Moreover, we allow those N_{Mh} channels to be split to serve a handoff request if no channel is available and we call this scheme the sub-rating technique. The new call rate in the macrocell λ_M is

$$\lambda_M = \frac{3\sqrt{3}}{2} R_M^2 \lambda_u D_{uM} \tag{5.14}$$

where R_M is the macrocell radius and D_{uM} is the average user density in the macrocell regions uncovered by microcells. Newly originated calls have residing time T_{n2} while the handoff requests in the macrocell have residing time T_{h2}. Both the new and handoff calls overflowed to the macrocell are treated as new calls in the macrocell layer since the occurrence of them is placed in an arbitrary position in the macrocell coverage area. Thus the cumulative distribution function (CDF) of the channel holding time $F_{T_{H2}}(t)$ is calculated as

$$F_{T_{H2}}(t) = \frac{\left[(\lambda_M + \lambda_{Moh})(1 - P_{BM}) + \lambda_{Mon}(1 - P_{BMon})\right] F_{T_{Hn2}}(t) + \lambda_{Mh}(1 - P_{fhM}) F_{T_{Hh2}}(t)}{(\lambda_M + \lambda_{Moh})(1 - P_{BM}) + \lambda_{Mon}(1 - P_{BMon}) + \lambda_{Mh}(1 - P_{fhM})}. \tag{5.15}$$

The average channel holding time in the macrocell $\bar{T}_{H2} = {}^{1}/_{\mu_{H2}}$ is given by

$$\bar{T}_{H2} = \frac{\frac{(\lambda_M+\lambda_{Moh})(1-P_{BM})+\lambda_{Mon}(1-P_{BMon})}{\mu_M+\mu_{n2}} + \frac{\lambda_{Mh}\left(1-P_{fhM}\right)}{\mu_M+\mu_{h2}}}{(\lambda_M + \lambda_{Moh})(1 - P_{BM}) + \lambda_{Mon}(1 - P_{BMon}) + \lambda_{Mh}(1 - P_{fhM})}. \tag{5.16}$$

The handoff rate in the macrocell is given by

$$\lambda_{Mh} = \frac{P_{N2}\left[(\lambda_M + \lambda_{Moh})(1 - P_{BM}) + \lambda_{Mon}(1 - P_{BMon})\right]}{1 - P_{H2}(1 - P_{fhM})} \tag{5.17}$$

From the state transition diagram shown in Fig. 5.7, the steady state probability, P_j, is given by

$$P_j = \begin{cases} \frac{(\lambda_M+\lambda_{Mo}+\lambda_{Mh})^j}{j!\mu_{H2}^j} P_0, \\ \quad 1 \leq j \leq N_M - N_{Mo} - N_{Mh} \\ \frac{(\lambda_M+\lambda_{Mo}+\lambda_{Mh})^{N_M-N_{Mo}-N_{Mh}} (\lambda_M+\lambda_{Moh}+\lambda_{Mh})^{j-(N_M-N_{Mo}-N_{Mh})}}{j!\mu_{H2}^j} P_0 \\ \quad N_M - N_{Mo} - N_{Mh} + 1 \leq j \leq N_M - N_{Mh} \\ \frac{(\lambda_M+\lambda_{Mo}+\lambda_{Mh})^{N_M-N_{Mo}-N_{Mh}} (\lambda_M+\lambda_{Moh}+\lambda_{Mh})^{N_{Mo}} \lambda_{Mh}^{j-(N_M-N_{Mh})}}{j!\mu_{H2}^j} P_0, \\ \quad N_M - N_{Mh} + 1 \leq j \leq N_M + N_{Mh} \end{cases} \tag{5.18}$$

where

$$\begin{aligned} P_0^{-1} \;=\; & \textstyle\sum_{k=0}^{N_M-N_{Mo}-N_{Mh}} \frac{(\lambda_M+\lambda_{Mo}+\lambda_{Mh})^k}{k!\mu_{H2}^k} \\ & + \textstyle\sum_{k=N_M-N_{Mo}-N_{Mh}+1}^{N_M-N_{Mh}} \frac{(\lambda_M+\lambda_{Mo}+\lambda_{Mh})^{N_M-N_{Mo}-N_{Mh}} (\lambda_M+\lambda_{Moh}+\lambda_{Mh})^{k-(N_M-N_{Mo}-N_{Mh})}}{k!\mu_{H2}^k} \\ & + \textstyle\sum_{k=N_M-N_{Mh}+1}^{N_M+N_{Mh}} \frac{(\lambda_M+\lambda_{Mo}+\lambda_{Mh})^{N_M-N_{Mo}-N_{Mh}} (\lambda_M+\lambda_{Moh}+\lambda_{Mh})^{N_{Mo}} \lambda_{Mh}^{k-(N_M-N_{Mh})}}{k!\mu_{H2}^k} \,. \end{aligned} \tag{5.19}$$

The rejection probability for those calls overflowed from a microcell is given by

$$P_{BMon} = \sum_{j=N_M-N_{Mo}-N_{Mh}}^{N_M+N_{Mh}} P_j, \tag{5.20}$$

while the blocking probability of new calls originated in the macrocell as well as the rejection probability of handoff calls overflowed to the macrocell are given by

$$P_{BM} = P_{BMoh} = \sum_{j=N_M-N_{Mh}}^{N_M+N_{Mh}} P_j \,. \tag{5.21}$$

The handoff failure probability of handoff calls at the macrocell level is given by

$$P_{fhM} = P_{N_M+N_{Mh}} \,. \tag{5.22}$$

The rate of overflow traffic from the macrocell layer to a spotbeam is given by

$$\lambda_{so} = \lambda_{son} + \lambda_{soh}, \tag{5.23}$$

where

$$\lambda_{son} = (\lambda_M P_{BM} + \lambda_{Mon} P_{BMon})\, C_M, \tag{5.24}$$

$$\lambda_{soh} = (\lambda_{Mh} P_{fhM} + \lambda_{Moh} P_{BMoh})\, C_M\,. \tag{5.25}$$

- **Spotbeam cell level**

In this level QPS is used for handoff calls in addition to schemes used in the macrocell level (i.e., RCS and SRS) to accommodate the high anticipated handoff rate. Within the overlapping area between spotbeam cells, handoff requests that find no available channels may wait with a FIFO discipline in a queue until a channel is released. Each spotbeam cell is allocated N_s channels. The new calls originating in a spotbeam area and overflow handoff calls are privileged over new calls overflowed from macrocells by allowing accessing to N_{so} channels. Also N_{sh} channels are reserved for handoff calls in this level, as shown in Fig. 5.2. The new call rate in spotbeam cell is

$$\lambda_s = \pi R_s^2 \lambda_u D_{us}, \tag{5.26}$$

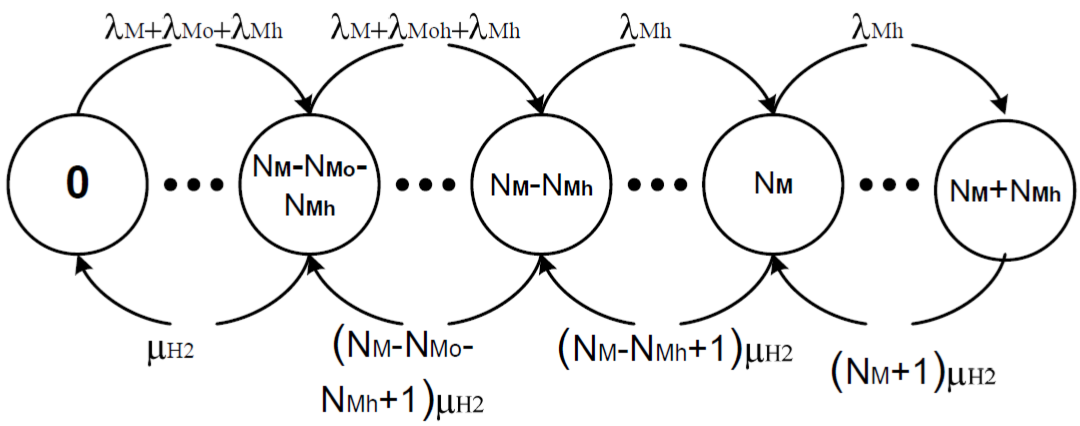


Figure 5.7: State transition diagram for macrocell.

where R_s is the spotbeam cell radius and D_{us} is the average user density in the spotbeam cell. Again both the new and handoff calls overflowed to the spotbeam cell are treated as new calls in the spotbeam cell layer since the occurrence of them is placed in an arbitrary position in the spotbeam cell coverage area. Hence, the average channel holding time in a spotbeam cell $\bar{T}_{H3} = {}^1/_{\mu_{H3}}$ is given by

$$\bar{T}_{H3} = \frac{\frac{(\lambda_s+\lambda_{soh})(1-P_{Bs})+\lambda_{son}(1-P_{Bson})}{\mu_M+\mu_{n3}} + \frac{\lambda_{sh}\left(1-P_{fhs}\right)}{\mu_M+\mu_{h3}}}{(\lambda_s + \lambda_{soh})(1 - P_{Bs}) + \lambda_{son}(1 - P_{Bson}) + \lambda_{sh}(1 - P_{fhs})}. \tag{5.27}$$

The handoff rate in the spotbeam is

$$\lambda_{sh} = \frac{P_{N3}\left[(\lambda_s + \lambda_{soh})(1 - P_{Bs}) + \lambda_{son}(1 - P_{Bson})\right]}{1 - P_{H3}(1 - P_{fhs})}. \tag{5.28}$$

From the state transition diagram displayed in Fig. 5.8 the steady state probability, P_j, is given by

$$P_j = \begin{cases} \frac{(\lambda_s+\lambda_{so}+\lambda_{sh})^j}{j!\mu_{H3}^j} P_0, \\ \quad 1 \le j \le N_s - N_{so} - N_{sh} \\ \frac{(\lambda_s+\lambda_{so}+\lambda_{sh})^{N_s-N_{so}-N_{sh}}(\lambda_s+\lambda_{soh}+\lambda_{sh})^{j-(N_s-N_{so}-N_{sh})}}{j!\mu_{H3}^j} P_0 \\ \quad N_s - N_{so} - N_{sh} + 1 \le j \le N_s - N_{sh} \\ \frac{(\lambda_s+\lambda_{so}+\lambda_{sh})^{N_s-N_{so}-N_{sh}}(\lambda_s+\lambda_{soh}+\lambda_{sh})^{N_{so}}\lambda_{sh}^{j-(N_s-N_{sh})}}{j!\mu_{H3}^j} P_0, \\ \quad N_s - N_{sh} + 1 \le j \le N_s + N_{sh} \\ \frac{(\lambda_s+\lambda_{so}+\lambda_{sh})^{N_s-N_{so}-N_{sh}}(\lambda_s+\lambda_{soh}+\lambda_{sh})^{N_{so}}\lambda_{sh}^{j-(N_s-N_{sh})}}{(N_s+N_{sh})!\mu_{H3}^{(N_s+N_{sh})}\prod_{i=1}^{j-(N_s+N_{sh})}\{(N_s+N_{sh})\mu_{H3}+i\mu_q\}} P_0, \\ \quad j \ge N_s + N_{sh} + 1 \end{cases} \tag{5.29}$$

where

$$\begin{aligned} P_0^{-1} = {} & \sum\nolimits_{k=0}^{N_s-N_{so}-N_{sh}} \frac{(\lambda_s+\lambda_{so}+\lambda_{sh})^k}{k!\mu_{H3}^k} \\ & + \sum\nolimits_{k=N_s-N_{so}-N_{sh}+1}^{N_s-N_{sh}} \frac{(\lambda_s+\lambda_{so}+\lambda_{sh})^{N_s-N_{so}-N_{sh}}(\lambda_s+\lambda_{soh}+\lambda_{sh})^{k-(N_s-N_{so}-N_{sh})}}{k!\mu_{H3}^k} \\ & + \sum\nolimits_{k=N_s-N_{sh}+1}^{N_s+N_{sh}} \frac{(\lambda_s+\lambda_{so}+\lambda_{sh})^{N_s-N_{so}-N_{sh}}(\lambda_s+\lambda_{soh}+\lambda_{sh})^{N_{so}}\lambda_{sh}^{k-(N_s-N_{sh})}}{k!\mu_{H3}^k}, \\ & + \sum\nolimits_{k=N_s+N_{sh}+1}^{\infty} \frac{(\lambda_s+\lambda_{so}+\lambda_{sh})^{N_s-N_{so}-N_{sh}}(\lambda_s+\lambda_{soh}+\lambda_{sh})^{N_{so}}\lambda_{sh}^{k-(N_s-N_{sh})}}{(N_s+N_{sh})!\mu_{H3}^{(N_s+N_{sh})}\prod_{i=1}^{k-(N_s+N_{sh})}\{(N_s+N_{sh})\mu_{H3}+i\mu_q\}}. \end{aligned} \tag{5.30}$$

The rejection probability of the new and handoff calls overflowed from the macrocell are, respectively, given by

$$P_{Bson} = \sum_{j=N_s-N_{so}-N_{sh}}^{\infty} P_j \tag{5.31}$$

$$P_{Bsoh} = \sum_{j=N_s-N_{sh}}^{\infty} P_j \tag{5.32}$$

The blocking probability of new calls delivered to the spotbeam, P_{Bs}, is equal by definition to P_{Bsoh}. The probability that a handoff attempt failed after joining the queue in position $k+1$ is [38, 39]

$$P_{fhsk} = 1 - \left[\frac{(N_s + N_{sh})\,\mu_{H3}}{(N_s + N_{sh})\,\mu_{H3} + \mu_q}\right] \prod_{i=1}^{k-N_{sh}} \left\{1 - \frac{\mu_q}{(N_s + N_{sh})\,\mu_{H3} + \mu_q}\left(\frac{1}{2}\right)^i\right\}. \tag{5.33}$$

Then the handoff failure probability is

$$Pfhs = \sum_{k=N_{sh}}^{\infty} P_{N_s+k} P_{fhsk}\,. \tag{5.34}$$

The proposed model assumed that there are three types of users:

1. **Terrestrial-only users** those access only the terrestrial subnetwork at the microcell and macrocell layers. The overall blocking and handoff failure probabilities for this type of users are calculated as follows

$$P_{Bto} = P_{Bm} P_{BMon}, \tag{5.35}$$

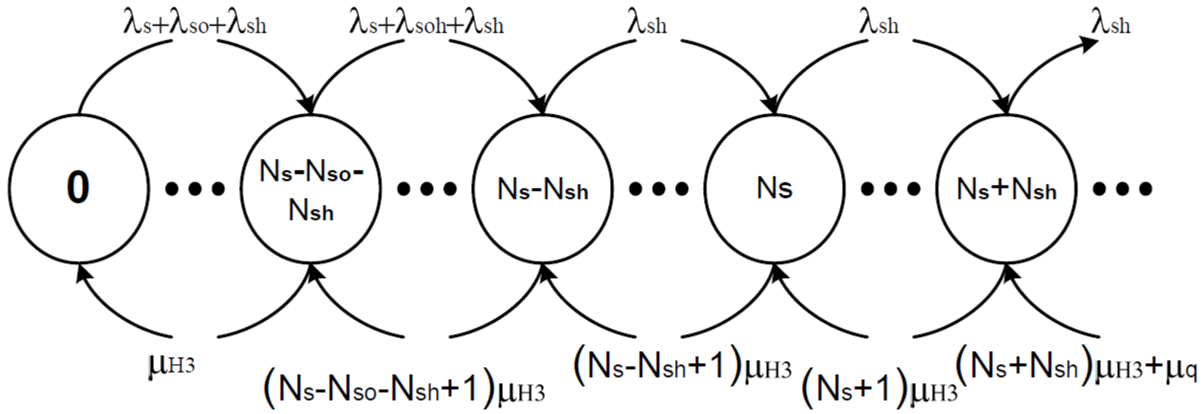


Figure 5.8: State transition diagram for spotbeam cell.

$$P_{fhto} = P_{fhm} P_{BMoh} \,. \tag{5.36}$$

The weighted blocking and handoff failure probabilities are

$$P_{Btw} = \frac{\lambda_m P_{Bm} C_m P_{BMon} + \lambda_M P_{BM}}{\lambda_m C_m + \lambda_M}, \tag{5.37}$$

$$P_{fhtw} = \frac{\lambda_{mh} P_{fhm} C_m P_{BMoh} + \lambda_{Mh} P_{fhM}}{\lambda_{mh} C_m + \lambda_{Mh}} \,. \tag{5.38}$$

2. **Satellite-only users** those access only to the satellite sub network. Both overall and weighted blocking and handoff failure probabilities for this type of users are the same as those for the satellite layer, i.e.,

$$P_{Bso} = P_{Bsw} = P_{Bs}, \tag{5.39}$$

$$P_{fhso} = P_{fhsw} = P_{fhs} \,. \tag{5.40}$$

3. **Dual-mode users** using dual-mode telephone sets, to enable them to access both the terrestrial sub network and the satellite sub network. The overall and weighted blocking and handoff failure probabilities for those users are given by

$$P_{Bdo} = P_{Bm} P_{BMon} P_{Bson}, \tag{5.41}$$

$$P_{fhdo} = P_{fhm} P_{BMoh} P_{Bsoh}, \tag{5.42}$$

$$P_{Bdw} = \frac{\left(\lambda_m P_{Bm} C_m P_{BMon} + \lambda_M P_{BM}\right) C_M P_{Bson} + \lambda_s P_{Bs}}{\lambda_m C_m C_M + \lambda_M C_M + \lambda_s}, \tag{5.43}$$

$$P_{fhdw} = \frac{\left(\lambda_{mh} P_{fhm} C_m P_{BMoh} + \lambda_{Mh} P_{fhM}\right) C_M P_{Bsoh} + \lambda_{sh} P_{fhs}}{\lambda_{mh} C_m C_M + \lambda_{Mh} C_M + \lambda_{sh}} \,. \tag{5.44}$$

Another important parameter for evaluating the system performance is the forced termination probability. It is defined as the probability that a nonblocked call is forced to terminate during its lifetime. It is important to distinguish between this probability and the handoff failure probability during a single handoff attempt [8]. We define first P_{F1}, P_{F2}, and P_{F3} as the noncompleted call probabilities because of handoff failure in micro- macro- and spotbeam cell layers, respectively, as

$$P_{F1} = \sum_{n=1}^{\infty} P_{N1} P_{fhm} \left[(1 - P_{fhm}) P_{H1} \right]^{n-1} = \frac{P_{N1} P_{fhm}}{1 - (1 - P_{fhm}) P_{H1}}, \tag{5.45}$$

$$P_{F2} = \frac{P_{N2} P_{fhM}}{1 - (1 - P_{fhM}) P_{H2}}, \tag{5.46}$$

$$P_{F3} = \frac{P_{N3} P_{fhs}}{1 - (1 - P_{fhs}) P_{H3}}.$$

The overall forced termination probability of the dual-mode users within a microcell, P_{Fd}, is calculated as the probability that a call is initiated in a microcell and noncompleted because of a handoff failure, or rejected in a microcell and accepted in a macrocell and then noncompleted because of a handoff failure, or finally rejected in both microcell and macrocell and accepted in a spotbeam cell and then noncompleted because of a handoff failure. To compute this we first define the forced termination probability for calls initiated in micro-, macro-, and spotbeam cells as P_{Fm}, P_{FM}, and P_{Fs}, respectively, (clearly P_{Fs} is equal to P_{F3}) these are given by

$$P_{Fm} = P_{F1} \left[P_{BMoh} + (1 - P_{BMoh}) P_{F2} \right] \left[P_{Bsoh} + (1 - P_{Bsoh}) P_{F3} \right], \tag{5.47}$$

$$P_{FM} = P_{F2} \left[P_{Bsoh} + (1 - P_{Bsoh}) P_{F3} \right]. \tag{5.48}$$

Then

$$P_{Fd} = \frac{P_{Fm} \left[1 - P_{Bm} \right] + P_{FM} \left[P_{Bm} (1 - P_{BMon}) \right] + P_{Fs} \left[P_{Bm} P_{BMon} (1 - P_{Bson}) \right]}{1 - P_{Bm} P_{BMon} P_{Bson}}. \tag{5.49}$$

Similarly, the overall forced termination probability of the terrestrial-only users within a microcell, P_{Ft}, is calculated as the probability that a call is initiated in a microcell and noncompleted because of a handoff failure, or is rejected in a microcell and accepted in a macrocell and then noncompleted because of a handoff failure, this is given by

$$P_{Ft} = \frac{P_{F1} \left[P_{BMoh} + (1 - P_{BMoh}) P_{F2} \right] (1 - P_{Bm}) + P_{F2} \left[P_{Bm} (1 - P_{BMon}) \right]}{1 - P_{Bm} P_{BMon}}. \tag{5.50}$$

Finally, the overall forced termination probability of the satellite-only users is calculated as the probability that a call is initiated in a spotbeam cell and noncompleted because of a handoff failure, i.e.,

$$P_{Fs} = P_{F3}\,. \tag{5.51}$$

The noncompleted call probability for a specific type of calls is defined as the fraction of new call attempts that will not be completed because of either blocking or unsuccessful handoff that is calculated for terrestrial-only users as

$$P_{nct} = P_{Bto} + P_{Ft}\left(1 - P_{Bto}\right), \tag{5.52}$$

for satellite-only users as

$$P_{ncs} = P_{Bs} + P_{Fs}\left(1 - P_{Bs}\right), \tag{5.53}$$

and, for the dual-mode users as

$$P_{ncd} = P_{Bdo} + P_{Fd}\left(1 - P_{Bdo}\right)\,. \tag{5.54}$$

5.3 Teletraffic Modelling of Voice and Data Services

In this section, both voice and data services are integrated over the proposed model. The required modifications are made to the previous detailed analysis of voice only service in order to accommodate the data service as well as the voice service.

5.3.1 Model description

The operation scenario can be described with the aid of Fig. 5.9 as follows:

1. Both voice and data services are encountered and offered for each cell-layer with different model parameters such as average call duration, average arrival call rates, and with different call-handling scheme.

2. Voice service, which is delay-sensitive, are given higher priority in the microcell layer

than data service. While data service may tolerate an acceptable delay level wait in a queue for channel release in both the macrocell and spotbeam cell layers.

3. Voice handoff requests are privileged with more reserved channels. Also the overflow handoff voice requests are privileged with more reserved channels than the overflow new voice call attempts.

4. Data messages are forced to wait in a queue for a channel in the macrocell layer while the number of waiting positions are limited to P, and in the spotbeam cell layer for an infinite waiting positions.

The above proposed architecture is attained to perform well with the challenge of mixing voice and data services because it permits data messages which is usually short (i.e., don't significantly increase the traffic load). In the same time, handoff voice requests are given priority than new ones by privilege them with more channels in micro- and macro- cells and further privileged by letting them to be wait in a queue in the spotbeam cell layer but with lower delay time than the data messages. This time is highly related to the overlapping areas between spotbeams.

5.3.2 Performance analysis

5.3.2.1 Microcell level

Each microcell is allocated N_m channel with fixed channel allocation (FCA) scheme. Out of those channels, N_{mh} is exclusively reserved for voice handoff requests. The voice and data new call rates in each microcell λ_{mv},λ_{md} are related to the microcell radius, R_m, average user density in the microcell, D_{um}, voice and data new call rates per user λ_{uv}, λ_{ud}, and the average fractions of voice and data users, α_v, α_d respectively as

$$\lambda_{mv} = \frac{3\sqrt{3}}{2} R_m^2 \lambda_{uv} D_{um} \alpha_v, \tag{5.55}$$

$$\lambda_{md} = \frac{3\sqrt{3}}{2} R_m^2 \lambda_{ud} D_{um} \alpha_d \,. \tag{5.56}$$

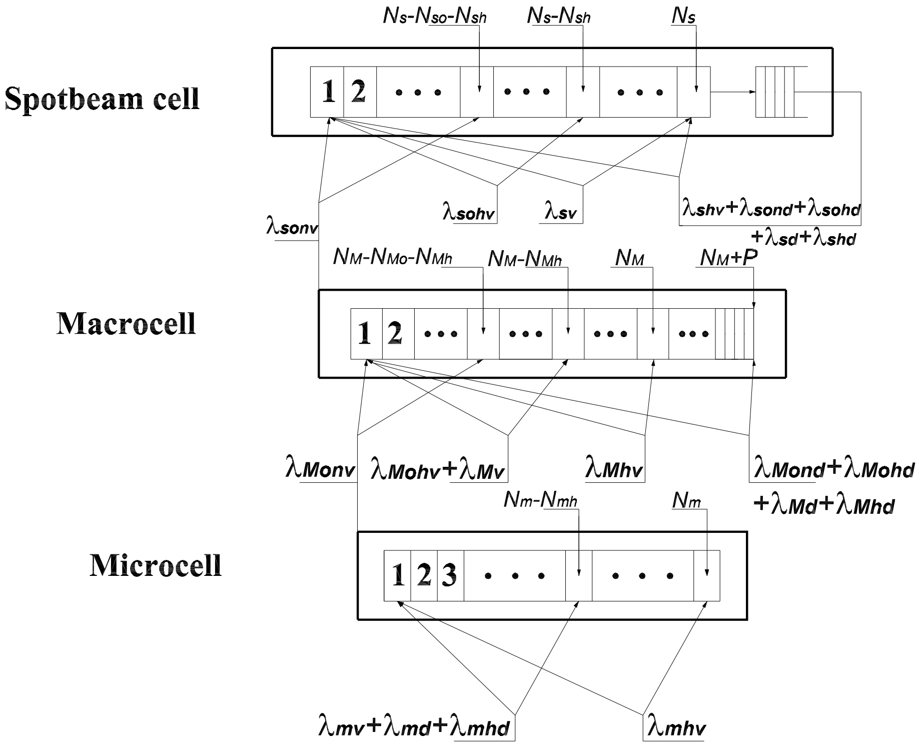


Figure 5.9: Channel allocation for new and handoff calls in each layer.

To calculate the average channel holding time, let the carried traffic rates for voice and data calls (new and handoff) are, respectively

$$\lambda_{C1m} = \lambda_{mv}\left(1 - P_{Bm}\right), \ \lambda_{C2m} = \lambda_{mhv}\left(1 - P_{fhm}\right),$$

$$\lambda_{C3m} = \lambda_{md}\left(1 - P_{Bm}\right), \ \text{and} \ \lambda_{C4m} = \lambda_{mhd}\left(1 - P_{Bm}\right) .$$

Then the average channel holding time is

$$\bar{T}_{H1} = \frac{\left[\frac{\lambda_{C1m}}{\mu_{Mv}+\mu_{n1}} + \frac{\lambda_{C2m}}{\mu_{Mv}+\mu_{h1}} + \frac{\lambda_{C3m}}{\mu_{Md}+\mu_{n1}} + \frac{\lambda_{C4m}}{\mu_{Md}+\mu_{h1}}\right]}{\lambda_{C1m} + \lambda_{C2m} + \lambda_{C3m} + \lambda_{C4m}} . \tag{5.57}$$

The probability that a successfully initiated voice call requires handoff is

$$P_{Nv1} = \mu_{n1}\left(\mu_{n1} + \mu_{Mv}\right)^{-1}, \tag{5.58}$$

while the probability that a handoff call will require more handoff is given by

$$P_{Hv1} = \mu_{h1} \left(\mu_{h1} + \mu_{Mv}\right)^{-1} \,. \tag{5.59}$$

Similarly for data calls

$$P_{Nd1} = \mu_{n1} \left(\mu_{n1} + \mu_{Md}\right)^{-1} , \tag{5.60}$$

$$P_{Hd1} = \mu_{h1} \left(\mu_{h1} + \mu_{Md}\right)^{-1} \,. \tag{5.61}$$

The handoff call rates for voice and data can be obtained as

$$\lambda_{mhv} = \frac{\lambda_{mv} \left(1 - P_{Bm}\right) P_{Nv1}}{1 - \left(1 - P_{fhm}\right) P_{Hv1}}, \tag{5.62}$$

$$\lambda_{mhd} = \frac{\lambda_{md} \left(1 - P_{Bm}\right) P_{Nd1}}{1 - \left(1 - P_{fhm}\right) P_{Hd1}} \,. \tag{5.63}$$

The aggregate microcell call rate is

$$\lambda_{mt} = \lambda_{mv} + \lambda_{md} + \lambda_{mhv} + \lambda_{mhd} \,.$$

The steady state probability, P_j, can be determined as

$$P_j = \begin{cases} \frac{\lambda_{mt}^j}{j!\mu_{H1}^j} P_0, \\ \qquad 1 \leq j \leq N_m - N_{mh} \\ \frac{\lambda_{mt}^{N_m - N_{mh}} \lambda_{mhv}^{j-(N_m - N_{mh})}}{j!\mu_{H1}^j} P_0, \\ \qquad N_m - N_{mh} + 1 \leq j \leq N_m \end{cases} \tag{5.64}$$

where

$$\begin{aligned} P_0^{-1} \quad = \quad & \textstyle\sum_{k=0}^{N_m - N_{mh}} \frac{\lambda_{mt}^k}{k!\mu_{H1}^k} \\ & + \textstyle\sum_{k=N_m - N_{mh}+1}^{N_m} \frac{\lambda_{mt}^{N_m - N_{mh}} \lambda_{mhv}^{k-(N_m - N_{mh})}}{k!\mu_{H1}^k} \,. \end{aligned} \tag{5.65}$$

The blocking probability of new voice and date calls as well as the data handoff failure probability, P_{Bm}, and voice handoff failure probability, P_{fhm}, are given by

$$P_{Bm} = \sum_{j=N_m-N_{mh}}^{N_m} P_j, \tag{5.66}$$

$$P_{fhm} = P_{N_m}\,. \tag{5.67}$$

The overflow rates of voice and data new and handoff calls directed to the next layer (i.e., macrocell) are, respectively, given by

$$\lambda_{Monv} = \lambda_{mv} P_{Bm} C_m,\ \lambda_{Mohv} = \lambda_{mhv} P_{fhm} C_m,\ \lambda_{Mond} = \lambda_{md} P_{Bm} C_m,\ \text{and}$$

$$\lambda_{Mohd} = \lambda_{mhd} P_{Bm} C_m\,.$$

5.3.2.2 Macrocell level

The voice and data new call rates in each macrocell λ_{Mv}, λ_{Md} are respectively given by

$$\lambda_{Mv} = \frac{3\sqrt{3}}{2} R_M^2 \lambda_{uv} D_{uM} \alpha_v, \tag{5.68}$$

$$\lambda_{Md} = \frac{3\sqrt{3}}{2} R_M^2 \lambda_{ud} D_{uM} \alpha_d\,. \tag{5.69}$$

The average channel holding time in the macrocell $\bar{T}_{H2} = {}^1\!/\!_{\mu_{H2}}$ is given by

$$\bar{T}_{H2} = \frac{\left[\frac{\lambda_{C1M}}{\mu_{Mv}+\mu_{n2}} + \frac{\lambda_{C2M}}{\mu_{Mv}+\mu_{h2}} + \frac{\lambda_{C3M}}{\mu_{Md}+\mu_{n2}} + \frac{\lambda_{C4M}}{\mu_{Md}+\mu_{h2}}\right]}{\lambda_{C1M} + \lambda_{C2M} + \lambda_{C3M} + \lambda_{C4M}}, \tag{5.70}$$

where

$$\lambda_{C1M} = \left(\lambda_{Mv} + \lambda_{Mohv}\right)\left(1 - P_{BMv}\right) + \lambda_{Monv}\left(1 - P_{BMonv}\right),\ \lambda_{C2M} = \lambda_{Mhv}\left(1 - P_{fhMv}\right),$$

$$\lambda_{C3M} = \left(\lambda_{Mond} + \lambda_{Mohd} + \lambda_{Md}\right)\left(1 - P_{tnMd}\right),\ \text{and}\ \lambda_{C4M} = \lambda_{Mhd}\left(1 - P_{thMd}\right)\,.$$

The handoff call rates for voice and data can be obtained as

$$\lambda_{Mhv} = \frac{P_{Nv2}\left[\left(\lambda_{Mv} + \lambda_{Mohv}\right)\left(1 - P_{BMv}\right) + \lambda_{Monv}\left(1 - P_{BMonv}\right)\right]}{1 - \left(1 - P_{fhMv}\right)P_{Hv2}}, \tag{5.71}$$

$$\lambda_{Mhd} = \frac{P_{Nv2}\left(\lambda_{Mond} + \lambda_{Mohd} + \lambda_{Mhd}\right)\left(1 - P_{tnMd}\right)}{1 - \left(1 - P_{thMd}\right)P_{Hd2}}. \tag{5.72}$$

The aggregate macrocell call rate is

$$\lambda_{Mt} = \lambda_{Monv} + \lambda_{Mond} + \lambda_{Mohv} + \lambda_{Mohd} + \lambda_{Mv} + \lambda_{Md} + \lambda_{Mhv} + \lambda_{Mhd}$$

Let $\lambda_{Mt1} = \lambda_{Mt} - \lambda_{Monv},\ \lambda_{Mt2} = \lambda_{Mt1} - \lambda_{Mohv} - \lambda_{Mv},$ and $\lambda_{Mt3} = \lambda_{Mt2} - \lambda_{Mhv}$.

The steady state probability, P_j, is given by

$$P_j = \begin{cases} \frac{\lambda_{Mt}^{j}}{j!\mu_{H2}^{j}}P_0, \\ \qquad 1 \le j \le N_M - N_{Mo} - N_{Mh} \\ \frac{\lambda_{Mt}^{N_M-N_{Mo}-N_{Mh}}\lambda_{Mt1}^{j-(N_M-N_{Mo}-N_{Mh})}}{j!\mu_{H2}^{j}}P_0 \\ \qquad N_M - N_{Mo} - N_{Mh} + 1 \le j \le N_M - N_{Mh} \\ \frac{\lambda_{Mt}^{N_M-N_{Mo}-N_{Mh}}\lambda_{Mt1}^{N_{Mo}}\lambda_{Mt2}^{j-(N_M-N_{Mh})}}{j!\mu_{H2}^{j}}P_0, \\ \qquad N_M - N_{Mh} + 1 \le j \le N_M \\ \frac{\lambda_{Mt}^{N_M-N_{Mo}-N_{Mh}}\lambda_{Mt1}^{N_{Mo}}\lambda_{Mt2}^{N_{Mh}}\lambda_{Mt3}^{j-N_M}}{N_M!\mu_{H2}^{N_M}\prod_{i=1}^{j-N_M}(N_M\mu_{H2}+i\mu_{q1})}P_0, \\ \qquad N_M + 1 \le j \le N_M + P \end{cases} \tag{5.73}$$

where

$$\mu_{q1} = \frac{\left(\lambda_{Md} + \lambda_{Mond} + \lambda_{Mohd}\right)\mu_{n2} + \lambda_{Mhd}\mu_{h2}}{\lambda_{Md} + \lambda_{Mond} + \lambda_{Mohd} + \lambda_{Mhd}},$$

and

$$\begin{aligned} P_0^{-1} \quad = \quad & \textstyle\sum_{k=0}^{N_M-N_{Mo}-N_{Mh}} \frac{\lambda_{Mt}^{k}}{k!\mu_{H2}^{k}} \\ & + \textstyle\sum_{k=N_M-N_{Mo}-N_{Mh}+1}^{N_M-N_{Mh}} \frac{\lambda_{Mt}^{N_M-N_{Mo}-N_{Mh}}\lambda_{Mt1}^{k-(N_M-N_{Mo}-N_{Mh})}}{k!\mu_{H2}^{k}} \\ & + \textstyle\sum_{k=N_M-N_{Mh}+1}^{N_M} \frac{\lambda_{Mt}^{N_M-N_{Mo}-N_{Mh}}\lambda_{Mt1}^{N_{Mo}}\lambda_{Mt2}^{k-(N_M-N_{Mh})}}{k!\mu_{H2}^{k}} \\ & + \textstyle\sum_{k=N_M+1}^{N_M+P} \frac{\lambda_{Mt}^{N_M-N_{Mo}-N_{Mh}}\lambda_{Mt1}^{N_{Mo}}\lambda_{Mt2}^{N_{Mh}}\lambda_{Mt3}^{k-N_M}}{N_M!\mu_{H2}^{N_M}\prod_{i=1}^{k-N_M}(N_M\mu_{H2}+i\mu_{q1})}. \end{aligned} \tag{5.74}$$

The blocking probability for those voice calls overflowed from a microcell is given by

$$P_{BMonv} = \sum_{j=N_M-N_{Mo}-N_{Mh}}^{N_M+P} P_j \tag{5.75}$$

while the blocking probability of new voice calls originated in the macrocell as well as the blocking probability of handoff voice calls overflowed to the macrocell are given by

$$P_{BMv} = P_{BMohv} = \sum_{j=N_M-N_{Mh}}^{N_M+P} P_j \,. \tag{5.76}$$

The handoff failure probability of handoff voice calls at the macrocell level is given by

$$P_{fhMv} = \sum_{j=N_M}^{N_M+P} P_j \,. \tag{5.77}$$

The transfer probability of new and handoff data calls are calculated as follows

$$P_{tnMd} = \sum_{j=N_M}^{N_M+P} P_j \left[1 - \left\{\frac{N_M\mu_{H2}}{N_M\mu_{H2}+\mu_{n2}} \prod_{i=1}^{j-N_M} \left(1 - \left(\frac{\mu_{n2}}{N_M\mu_{H2}+\mu_{n2}}\right)\left(\frac{1}{2}\right)^i\right)\right\}\right], \tag{5.78}$$

$$P_{thMd} = \sum_{j=N_M}^{N_M+P} P_j \left[1 - \left\{\frac{N_M\mu_{H2}}{N_M\mu_{H2}+\mu_{h2}} \prod_{i=1}^{j-N_M} \left(1 - \left(\frac{\mu_{h2}}{N_M\mu_{H2}+\mu_{h2}}\right)\left(\frac{1}{2}\right)^i\right)\right\}\right]. \tag{5.79}$$

The overflow rates of voice and data new and handoff calls directed to the next layer (i.e., spotbeam cell) are, respectively, given by

$$\lambda_{sonv} = \left(\lambda_{Monv}P_{BMonv} + \lambda_{Mv}P_{BMv}\right)C_M, \;\; \lambda_{sohv} = \left(\lambda_{Mohv}P_{BMv} + \lambda_{Mhv}P_{fhMv}\right)C_M,$$

$$\lambda_{sond} = \left(\lambda_{Mond} + \lambda_{Md}\right)P_{tnMd}C_M, \;\text{ and }\; \lambda_{sohd} = \left(\lambda_{Mohv}P_{tnMd} + \lambda_{Mhd}P_{thMd}\right)C_M \,.$$

5.3.2.3 Spotbeam cell level

The voice and data new call rates in each macrocell λ_{sv},λ_{sd} are respectively given by

$$\lambda_{sv} = \pi R_s^2 \lambda_{uv} D_{us} \alpha_v \tag{5.80}$$

$$\lambda_{sd} = \pi R_s^2 \lambda_{ud} D_{us} \alpha_d \tag{5.81}$$

The average channel holding time $\bar{T}_{H3} = {}^{1}/_{\mu_{H3}}$ is given by

$$\bar{T}_{H3} = \frac{\left[\frac{\lambda_{C1s}}{\mu_{Mv}+\mu_{n3}} + \frac{\lambda_{C2s}}{\mu_{Mv}+\mu_{h3}} + \frac{\lambda_{C3s}}{\mu_{Md}+\mu_{n3}} + \frac{\lambda_{C4s}}{\mu_{Md}+\mu_{h3}}\right]}{\lambda_{C1s} + \lambda_{C2s} + \lambda_{C3s} + \lambda_{C4s}}, \tag{5.82}$$

where

$$\lambda_{C1s} = \lambda_{sonv}\left(1 - P_{Bsonv}\right) + \lambda_{sohv}\left(1 - P_{Bsohv}\right) + \lambda_{sv}\left(1 - P_{Bsv}\right), \; \lambda_{C2s} = \lambda_{shv}\left(1 - P_{fhsv}\right),$$

$$\lambda_{C3s} = \left(\lambda_{sond} + \lambda_{sohd} + \lambda_{sd}\right)\left(1 - P_{tnsd}\right), \text{ and } \lambda_{C4s} = \lambda_{shd}\left(1 - P_{thsd}\right) .$$

The handoff call rates for voice and data can be obtained as

$$\lambda_{shv} = \frac{P_{Nv3}\left[\lambda_{sv}\left(1 - P_{Bsv}\right) + \lambda_{sonv}\left(1 - P_{Bsonv}\right) + \lambda_{sohv}\left(1 - P_{Bsohv}\right)\right]}{1 - \left(1 - P_{fhsv}\right) P_{Hv3}}, \tag{5.83}$$

$$\lambda_{shd} = \frac{P_{Nd3}\left(\lambda_{sond} + \lambda_{sohd} + \lambda_{sd}\right)\left(1 - P_{tnsd}\right)}{1 - \left(1 - P_{thsd}\right) P_{Hd3}} . \tag{5.84}$$

The aggregate spotbeam cell call rate is

$$\lambda_{st} = \lambda_{sonv} + \lambda_{sond} + \lambda_{sohv} + \lambda_{sohd} + \lambda_{sv} + \lambda_{sd} + \lambda_{shv} + \lambda_{shd}$$

$$\text{Let } \lambda_{st1} = \lambda_{st} - \lambda_{sonv}, \; \lambda_{st2} = \lambda_{st1} - \lambda_{sohv}, \text{ and } \lambda_{st3} = \lambda_{st2} - \lambda_{sv} .$$

The steady state probability, P_j, is given by

$$P_j = \begin{cases} \frac{\lambda_{st}^{j}}{j!\mu_{H3}^{j}} P_0, \\ \quad 1 \leq j \leq N_s - N_{so} - N_{sh} \\ \frac{\lambda_{st}^{N_s-N_{so}-N_{sh}} \lambda_{st1}^{j-(N_s-N_{so}-N_{sh})}}{j!\mu_{H3}^{j}} P_0 \\ \quad N_s - N_{so} - N_{sh} + 1 \leq j \leq N_s - N_{sh} \\ \frac{\lambda_{st}^{N_s-N_{so}-N_{sh}} \lambda_{st1}^{N_{so}} \lambda_{st2}^{j-(N_s-N_{sh})}}{j!\mu_{H3}^{j}} P_0, \\ \quad N_s - N_{sh} + 1 \leq j \leq N_s \\ \frac{\lambda_{st}^{N_s-N_{so}-N_{sh}} \lambda_{st1}^{N_{so}} \lambda_{st2}^{N_{sh}} \lambda_{st3}^{j-N_s}}{N_s!\mu_{H3}^{N_s} \prod_{i=1}^{j-N_s}(N_s\mu_{H3}+i\mu_{q2})} P_0, \\ \quad j \geq N_s + 1 \end{cases} \tag{5.85}$$

where

$$\begin{aligned} P_0^{-1} \; = \; & \sum_{k=0}^{N_s-N_{so}-N_{sh}} \frac{\lambda_{st}^{k}}{k!\mu_{H3}^{k}} \\ & + \sum_{k=N_s-N_{so}-N_{sh}+1}^{N_s-N_{sh}} \frac{\lambda_{st}^{N_s-N_{so}-N_{sh}} \lambda_{st1}^{k-(N_s-N_{so}-N_{sh})}}{k!\mu_{H3}^{k}} \\ & + \sum_{k=N_s-N_{sh}+1}^{N_s} \frac{\lambda_{st}^{N_s-N_{so}-N_{sh}} \lambda_{st1}^{N_{so}} \lambda_{st2}^{k-(N_s-N_{sh})}}{k!\mu_{H3}^{k}} \\ & + \sum_{k=N_s+1}^{\infty} \frac{\lambda_{st}^{N_s-N_{so}-N_{sh}} \lambda_{st1}^{N_{so}} \lambda_{st2}^{N_{sh}} \lambda_{st3}^{k-N_s}}{N_s!\mu_{H3}^{N_s} \prod_{i=1}^{k-N_s}(N_s\mu_{H3}+i\mu_{q2})} \, . \end{aligned} \tag{5.86}$$

The average departure rate of the mixed voice and data can be computed as [41]

$$\mu_{q2} = \frac{\lambda_{shv}\mu_{qv} + (\lambda_{sond} + \lambda_{sohd} + \lambda_{sd})\,\mu_{n3} + \lambda_{shd}\mu_{h3}}{\lambda_{shv} + \lambda_{sond} + \lambda_{sohd} + \lambda_{sd} + \lambda_{shd}} \, .$$

The blocking probability of the new and handoff voice calls overflowed from macrocell are, respectively, given by

$$P_{Bsonv} = \sum_{j=N_s-N_{so}-N_{sh}}^{\infty} P_j, \tag{5.87}$$

$$P_{Bsohv} = \sum_{j=N_s-N_{sh}}^{\infty} P_j, \tag{5.88}$$

while the blocking probability of new voice calls originated in the spotbeam cell is given by

$$P_{Bsv} = \sum_{j=N_s}^{\infty} P_j \, . \tag{5.89}$$

The handoff failure probability of handoff voice calls at the spotbeam cell level is given by

$$P_{fhsv} = \sum_{j=N_s}^{\infty} P_j \left[1 - \left\{ \frac{N_s\mu_{H3}}{N_s\mu_{H3} + \mu_{qv}} \prod_{i=1}^{j-N_s} \left(1 - \left(\frac{\mu_{qv}}{N_s\mu_{H3} + \mu_{qv}}\right)\left(\frac{1}{2}\right)^i\right)\right\}\right], \tag{5.90}$$

while the transfer probability of new and handoff data calls are calculated as follows

$$P_{tnsd} = \sum_{j=N_s}^{\infty} P_j \left[1 - \left\{ \frac{N_s\mu_{H3}}{N_s\mu_{H3} + \mu_{n3}} \prod_{i=1}^{j-N_s} \left(1 - \left(\frac{\mu_{n3}}{N_s\mu_{H3} + \mu_{n3}}\right)\left(\frac{1}{2}\right)^i\right)\right\}\right], \tag{5.91}$$

$$P_{thsd} = \sum_{j=N_s}^{\infty} P_j \left[1 - \left\{ \frac{N_s\mu_{H3}}{N_s\mu_{H3} + \mu_{h3}} \prod_{i=1}^{j-N_s} \left(1 - \left(\frac{\mu_{h3}}{N_s\mu_{H3} + \mu_{h3}}\right)\left(\frac{1}{2}\right)^i\right)\right\}\right]. \tag{5.92}$$

Chapter 6

Results and Discussion

6.1 Numerical Results for Providing Voice Service Only

For the proposed integrated architecture, the radii of the microcells, macrocells, and spotbeam cells are 1, 5, and 70 km, respectively. Every 10 microcells are overlaid by a macrocell and every 30 macrocells are embedded in a spotbeam cell. Channels allocated for the microcell, macrocell and spotbeam cell are 16, 32 and 56, respectively. Two channels are reserved in each microcell for exclusive usage by handoff calls, while 4 channels per macrocell are privileged to accommodate the handoff traffic overflowed to it from the underlay microcells. Another 4 channels are reserved for handoff requests in that layer. Similarly 7 channels per spotbeam cell are privileged for the overflowed handoff traffic from the underlay macrocells and another 7 channels are reserved for handoff requests in that layer.

The average call duration is 120 s. The average user densities in micro-, macro-, and spotbeam cells are assumed to be 100, 40, 6 user/km^2 respectively. The speed of a mobile station in a micro- a macro- and a spotbeam cells is assumed to be uniformly distributed with a mean of 20, 45, and 60 km/hr., respectively. The residing times of new and handoff calls in a micro- a macro- and a spotbeam cells are obtained as [34]. The mean dwell time for the handoff attempt in the spotbeam overlapping areas $\bar{T}_q = 1/\mu_q$ is assumed to $\bar{T}_{H3}/10$.

Results for this situation are illustrated in Fig. 6.1. It is noted that P_{Bm} is the lowest because there is no overflow to this layer. The next is P_{BM}, then P_{BMon} because there is some channels N_{Mo} privileged for macrocell new call over that overflowed to it as new calls. Also,

P_{Bs} is lower than P_{Bson} for the same reason. In Fig. 6.2 the overall blocking probabilities for each user type is shown while Fig 6.3 gives the weighted blocking probabilities for each user type.

Fig. 6.4, Fig. 6.5, and Fig. 6.6 display the effect of using different priority schemes in each layer represented as handoff failure for each layer, overall, and weighted handoff failure probabilities for each user type. The forced termination and noncompleted call probabilities for each user type are given in Fig. 6.7 and Fig. 6.8, respectively. Fig. 6.9 displays the effect of using SRS on the handoff failure probabilities in the macrocell and spotbeam cell levels. It can be noted that the probabilities are significantly reduced with SRS.

6.2 Parametric Effects

In this section, the effects of parameters on the performance measures are discussed and analyzed, to attain the required goals of achieving and enhancing the proposed model and assist the system designers to reach their high performance with different modifications.

6.2.1 Effects of reserved channel scheme, sub-rating scheme, and queueing priority scheme

Shown in Fig. 6.10, the effect of reserved channel scheme used in the microcell layer. While this scheme reduces the handoff failure probability in the microcell layer, it slightly increases the blocking probability in this layer so it is suitable to use only this scheme in the lowest hierarchical level (microcell layer).

In Fig. 6.11, both the RCS and the sub-rating scheme are applied to the macrocell layer. It is shown that the effect of sub-rating is significantly reducing the handoff failure probability (P_{fhM}) despite of the high load resulting from the overflow traffic. Again the blocking probability is slightly increased, so it is recommended to use this scheme in relieving the peak traffic in this layer.

The effects of RCS, SRS, and the queueing priority scheme are shown in Fig. 6.12, it is noted that the gap between the blocking and handoff failure probabilities in this layer

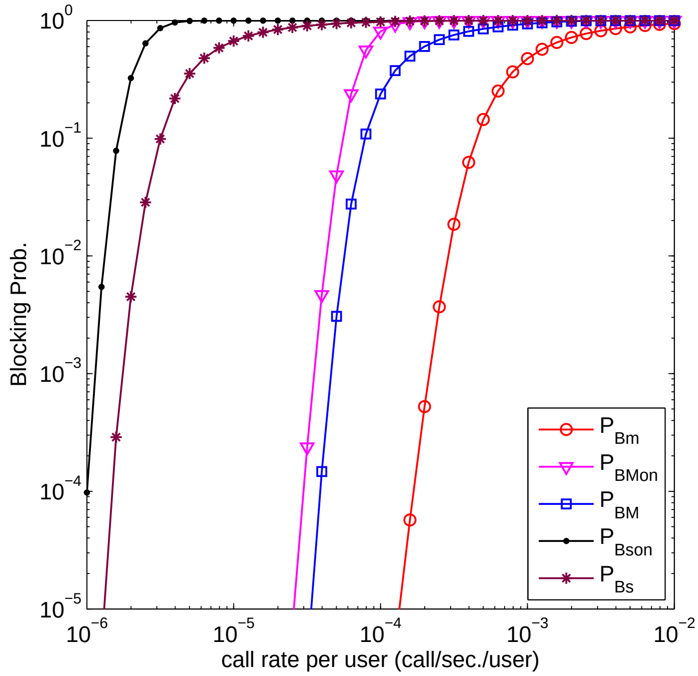


Figure 6.1: The blocking and overflow rejection probabilities of each layer as a function of call rate per user.

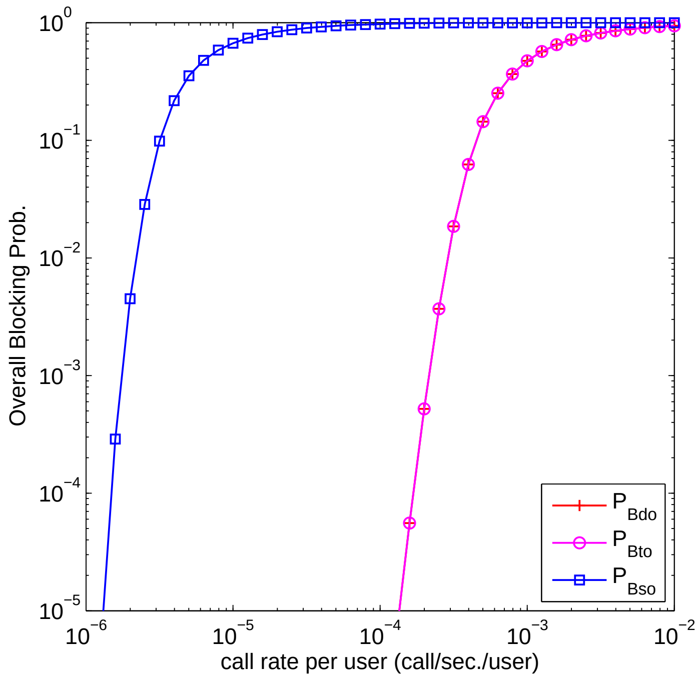


Figure 6.2: The overall blocking probabilities of each user type as a function of call rate per user.

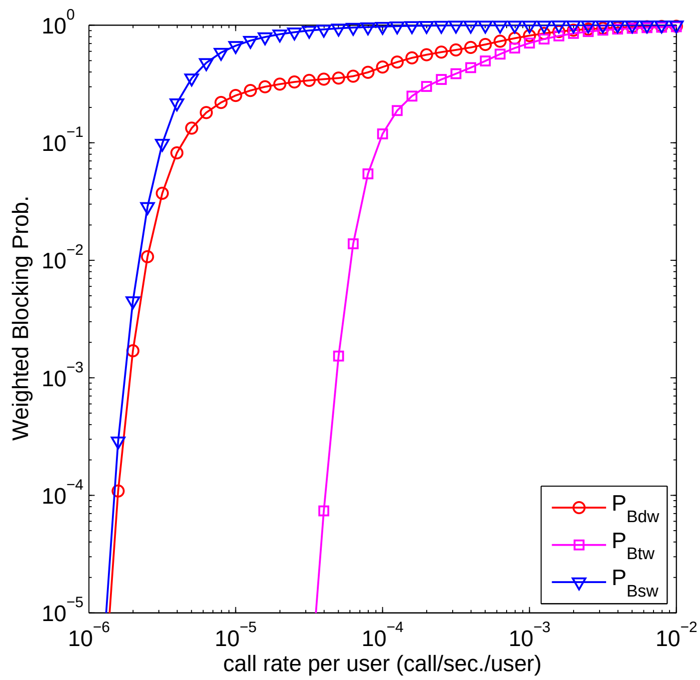


Figure 6.3: The weighted blocking probabilities of each user type as a function of call rate per user.

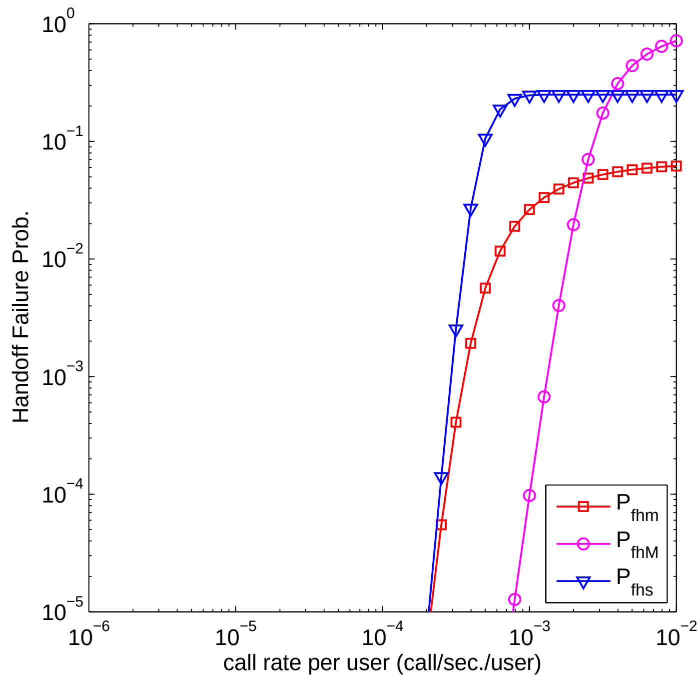


Figure 6.4: The handoff failure probabilities of each layer as a function of call rate per user.

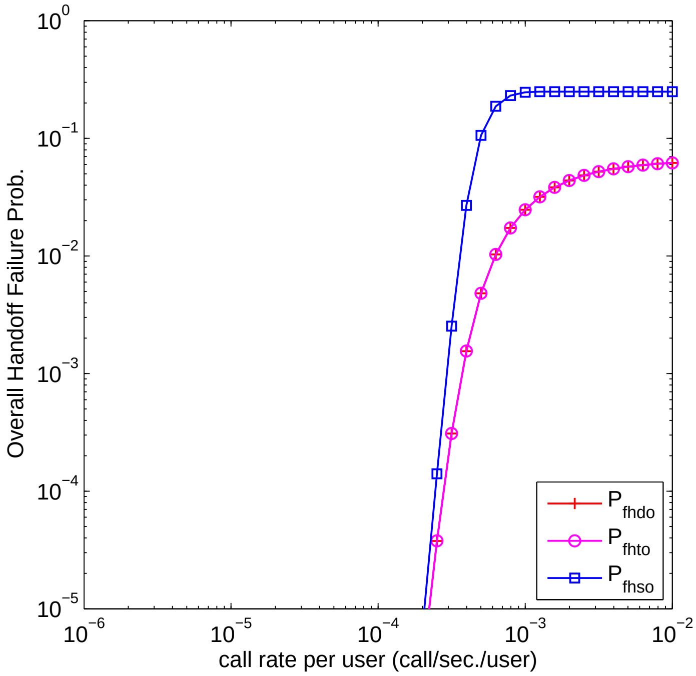


Figure 6.5: The overflow handoff failure probabilities of each user type as a function of call rate per user.

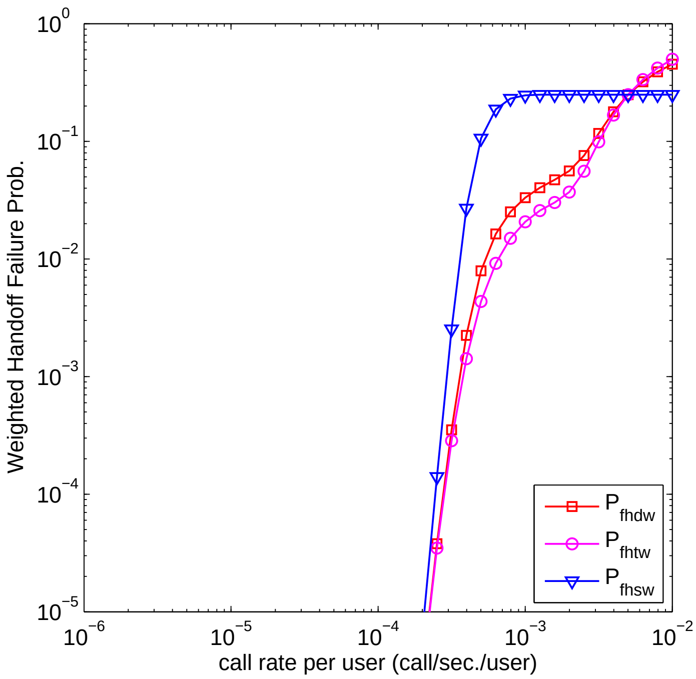


Figure 6.6: The weighted handoff failure probabilities of each user type as a function of call rate per user.

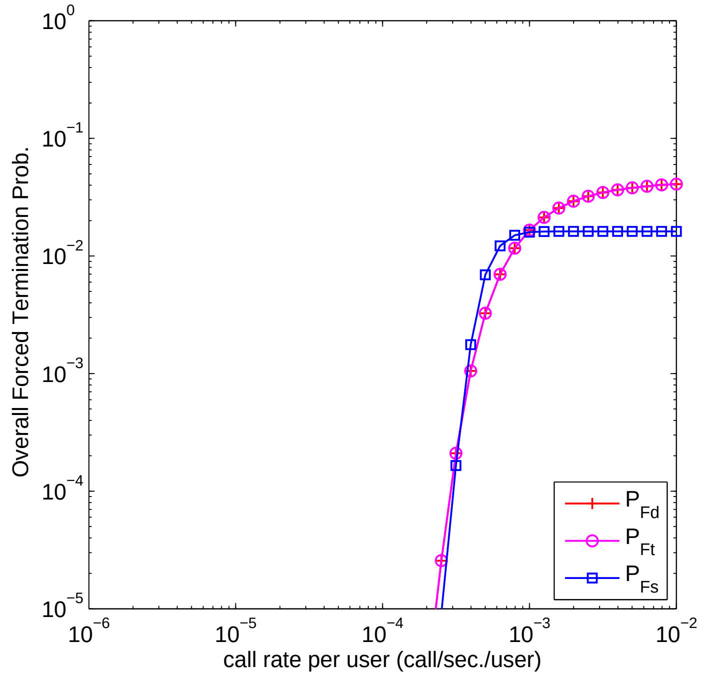


Figure 6.7: The overall forced termination probabilities of each user type as a function of call rate per user.

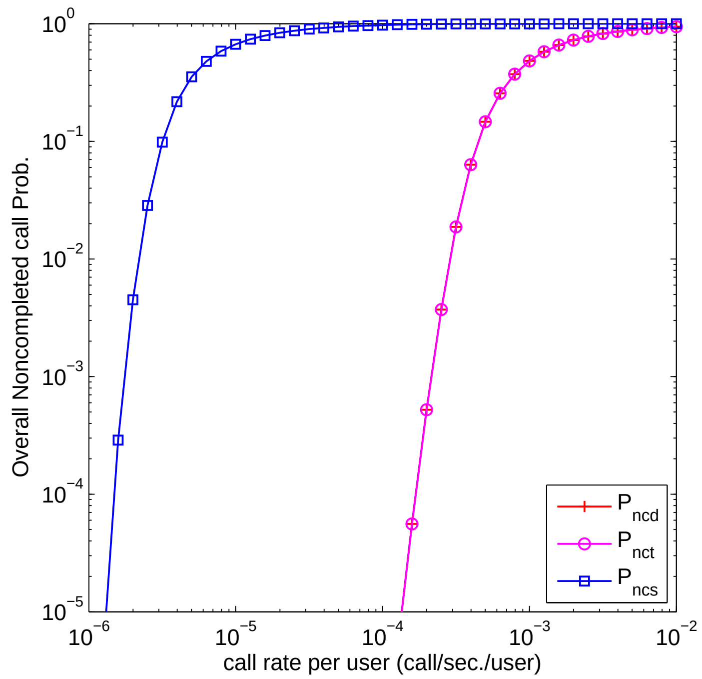


Figure 6.8: The noncompleted call probabilities of each user type as a function of call rate per user.

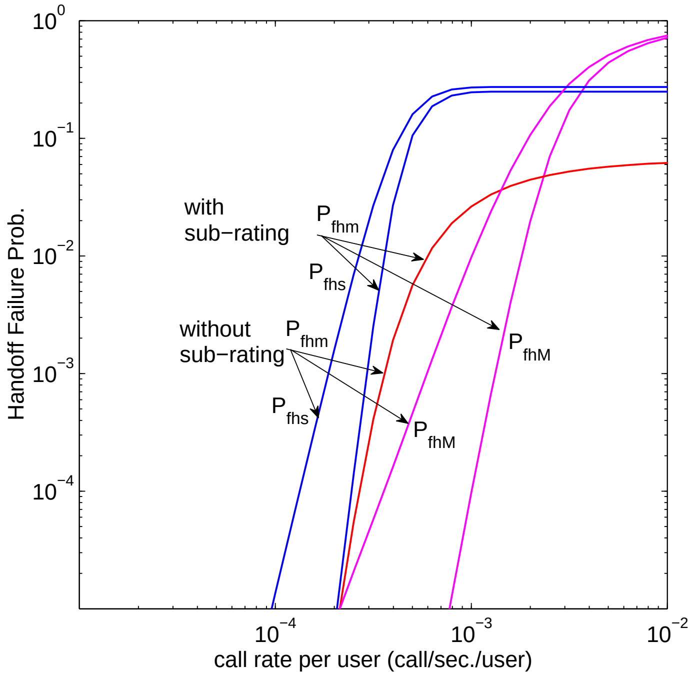


Figure 6.9: The handoff failure probabilities with and without SRS as a function of call rate per user.

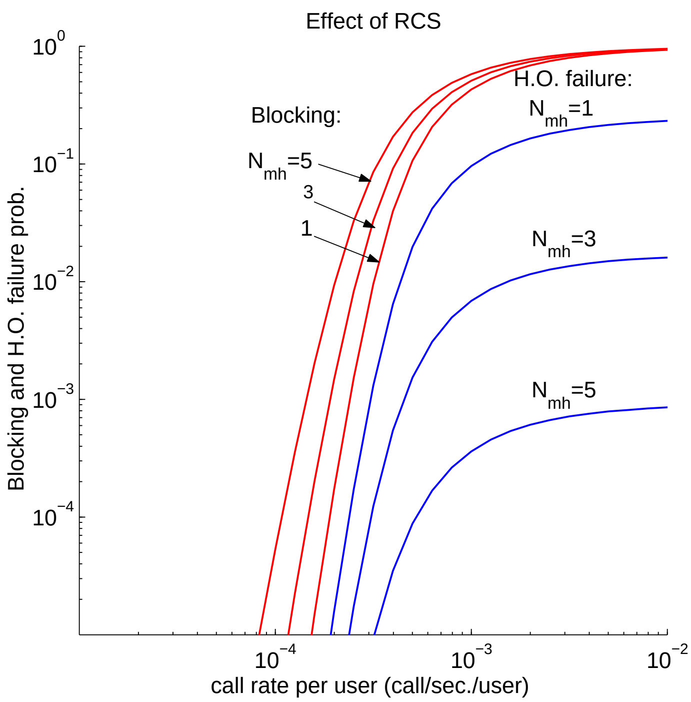


Figure 6.10: The blocking and handoff failure probabilities in the microcell with N_{mh} =1, 3, & 5.

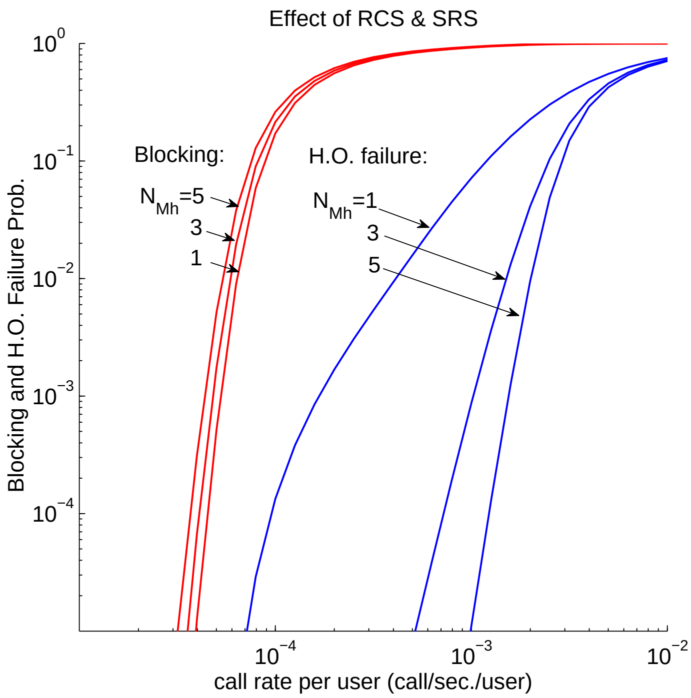


Figure 6.11: The blocking and handoff failure probabilities in the macrocell with N_{Mh} =1, 3, & 5.

(spotbeam layer) is increased. So by using the different priority schemes as in the above scenario, we can accommodate the handoff traffic in a superior fashion while handling the new traffic with an acceptable degree of GOS.

6.2.2 Effect of number of overlaid microcells

Fig. 6.13 and Fig. 6.14, indicate the effect of varying the number of microcells overlaid by a macrocell C_m on both the blocking and handoff failure probabilities respectively. It is shown that both P_{Bm} and P_{fhm} are not affected, because there is no change occurs for the microcell layer. But as C_m increases from 5, 10, and 15 microcells per macrocell, all of P_{BM}, P_{fhM}, P_{Bs} and P_{fhs} are increased.

6.2.3 Effect of number of overlaid macrocells

Fig. 6.15 and Fig. 6.16 show the effect of varying the number of macrocells embedded in a spotbeam cell C_M on both the blocking and handoff failure probabilities respectively. It is shown that all of P_{Bm}, P_{fhm}, P_{BM} and P_{fhM} are not affected, because there is no change for these two layers (microcell and macrocell layers). But as C_M increases from 20, 30, and 40

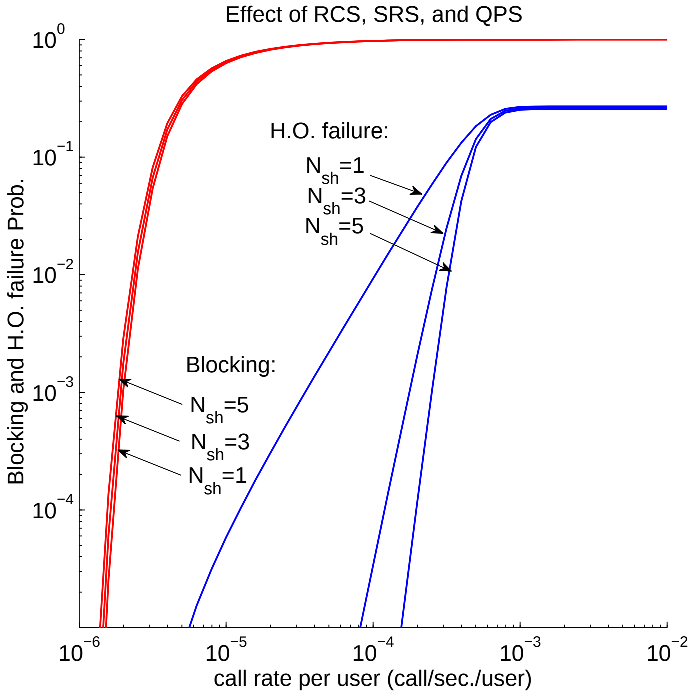


Figure 6.12: The blocking and handoff failure probabilities in the spotbeam cell with N_{sh} =1, 3, & 5.

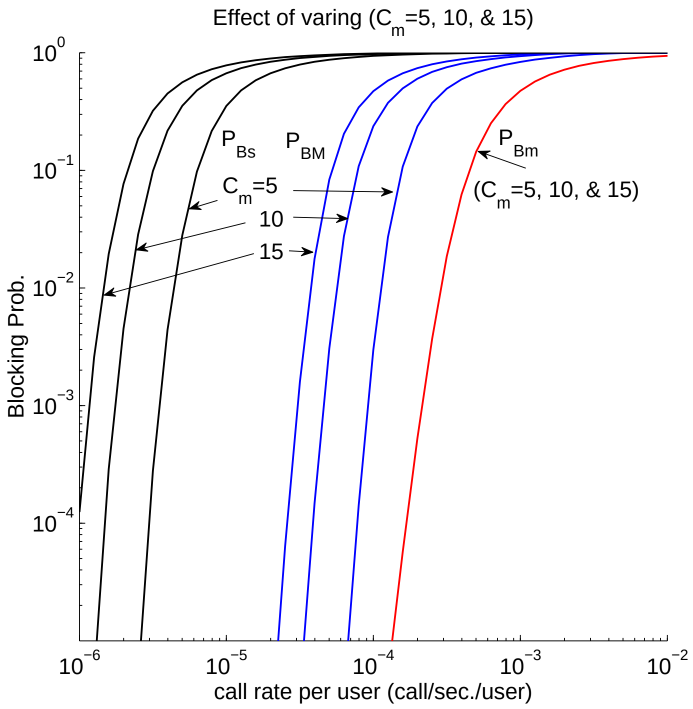


Figure 6.13: The blocking probabilities of each layer with C_m =5, 10, & 15.

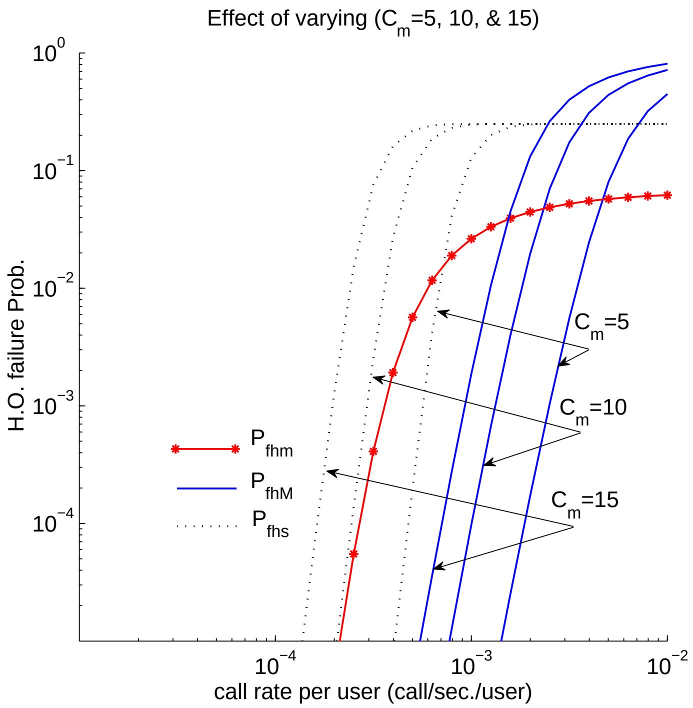


Figure 6.14: The handoff failure probabilities of each layer with C_m =5, 10, & 15.

macrocells per spotbeam cell, both P_{Bs} and P_{fhs} are increased.

6.2.4 Effect of infinite queue

It is shown in Fig. 6.17, the effect of implementing an infinite queue in the spotbeam cell layer on the handoff failure probability P_{fhs}. If we put N_{sh}=0, then the effect of the queue appears. It highly reduces the failure handoff probability in the spotbeam cell while, the blocking probability P_{Bs} is not affected.

6.2.5 Effect of handoff area size

Fig. 6.18 shows the effect of handoff area size, $\bar{T}_q$ on the handoff failure probability P_{fhs}. As the average residing time in the overlapping area increases from $\bar{T}_{H3}/6$, $\bar{T}_{H3}/4$, to $\bar{T}_{H3}/2$, the handoff failure probability in the spotbeam cell layer is decreased.

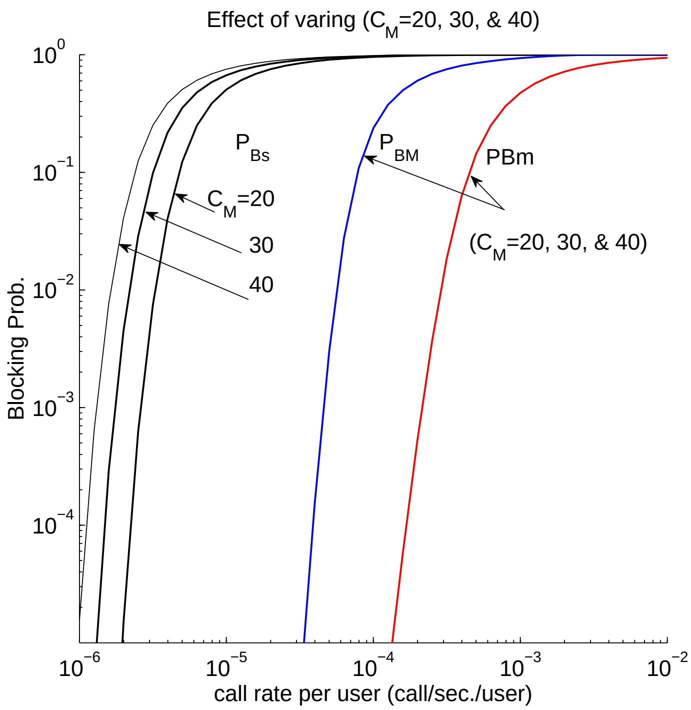


Figure 6.15: The blocking probabilities of each layer with C_M =20, 30, & 40.

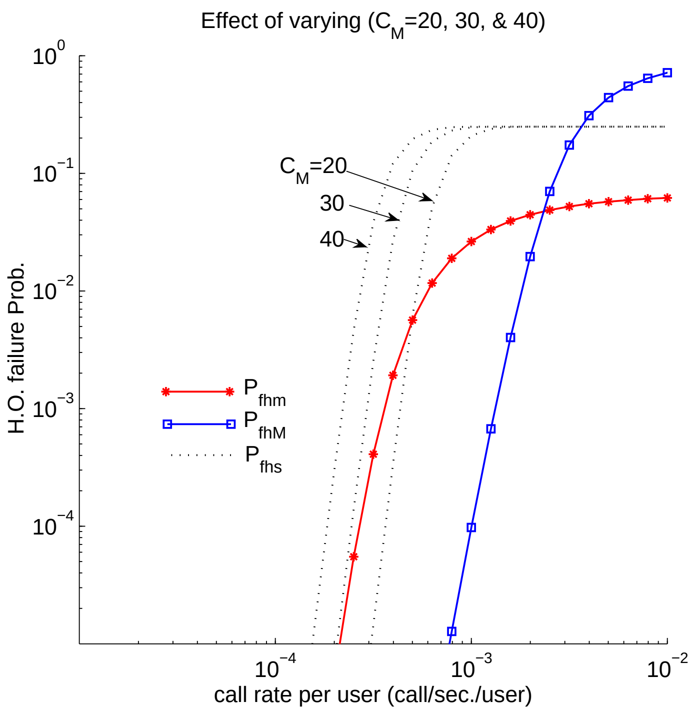


Figure 6.16: The handoff failure probabilities of each layer with C_M =20, 30, & 40.

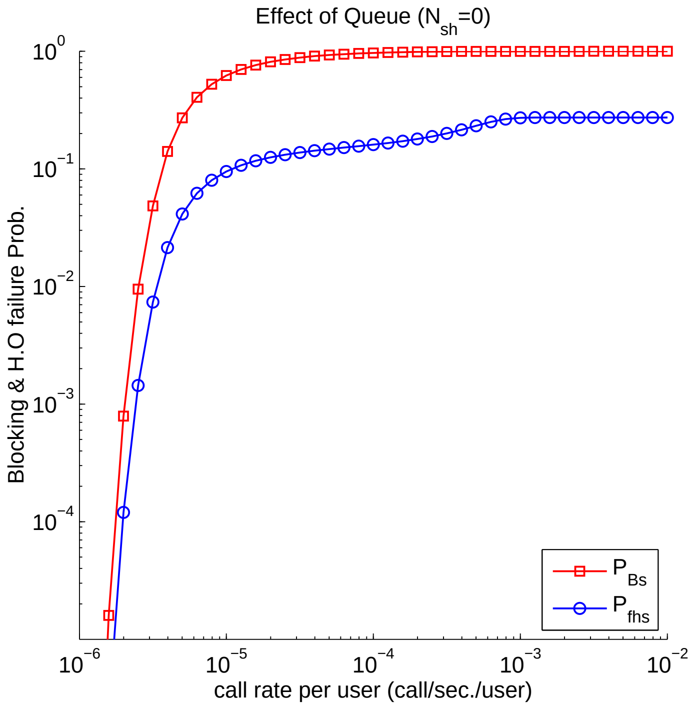


Figure 6.17: The blocking and handoff failure probabilities of spotbeam cell layer.

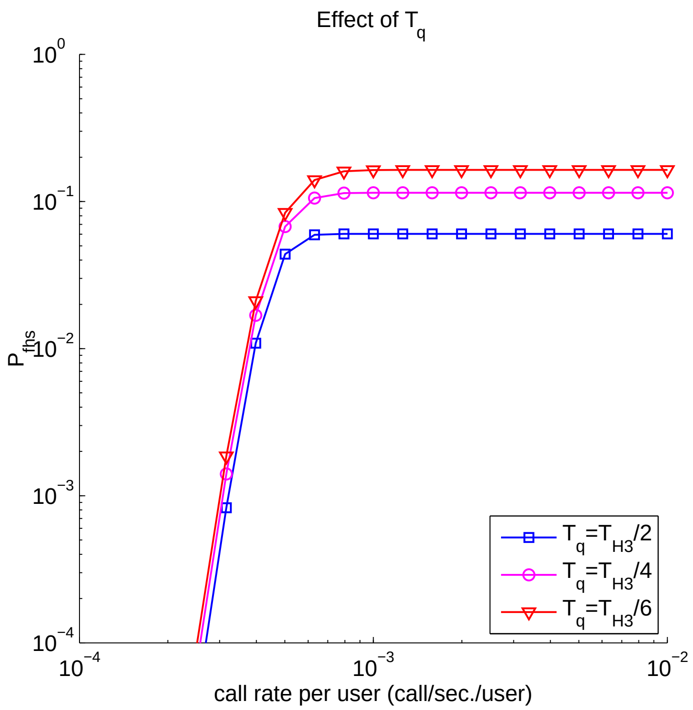


Figure 6.18: The handoff failure probabilities of spotbeam cell layer as T_q vary from $T_{H3}/6$, $T_{H3}/4$, and $T_{H3}/2$.

6.3 Numerical Results for Voice/Data Integration

The results of the integrated voice/data model are given in this section, indicating the performance of these services as the blocking probabilities and the handoff failure probabilities.

All the system parameters are as that of the voice only model, with 10 s average data call duration. The number of waiting positions per macrocell is assumed to be 5. The average fraction of voice users is 0.7 and the average fraction of data users is 0.3.

Results for this situation are illustrated in Fig. 6.19, Fig. 6.20 and Fig. 6.21 for micro-, macro-, and spotbeam cell respectively.

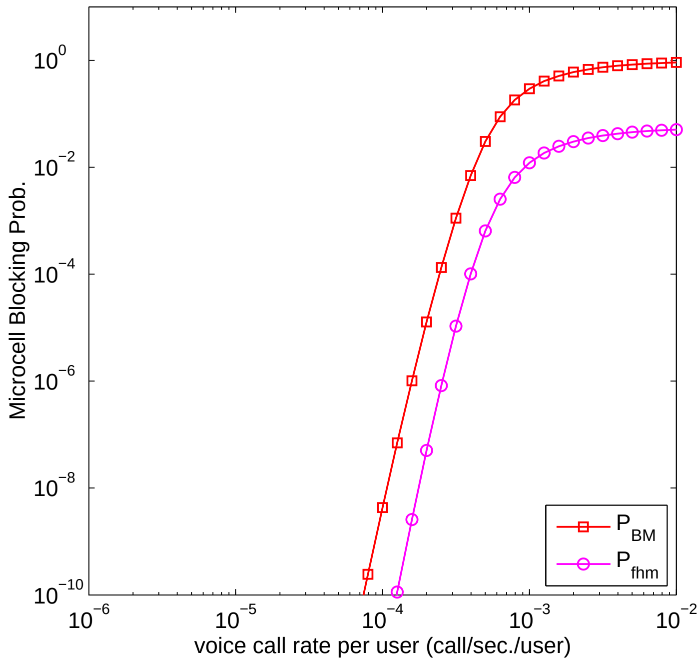


Figure 6.19: The blocking probabilities of the microcell layer.

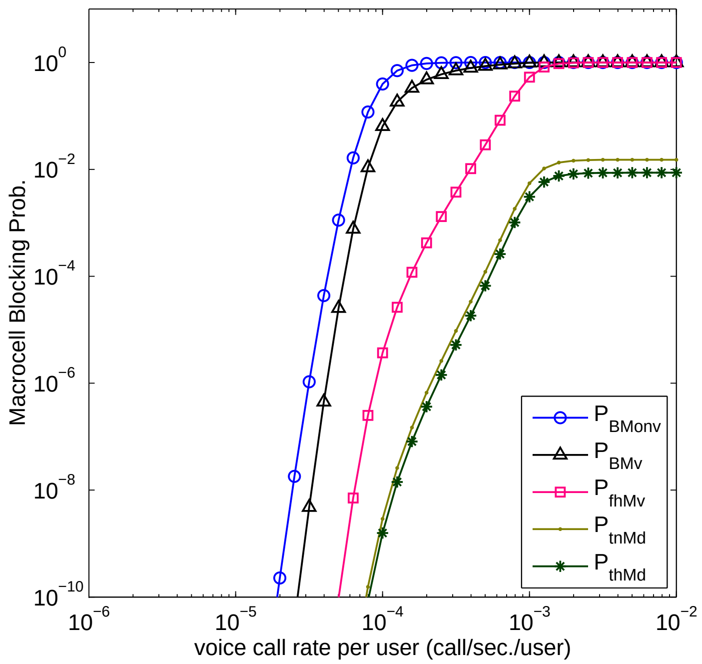


Figure 6.20: The blocking probabilities of the macrocell layer.

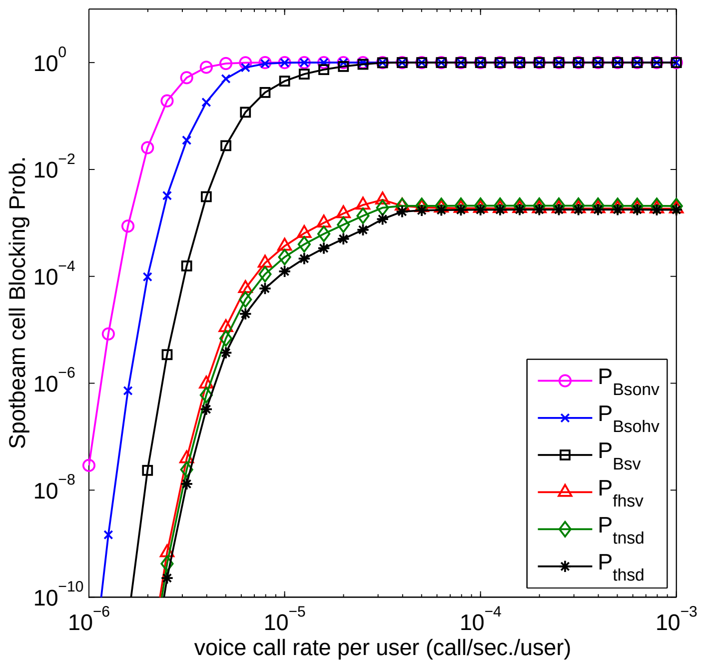


Figure 6.21: The blocking probabilities of the spotbeam cell layer.

Chapter 7

Conclusion and Future Work

7.1 Conclusion

The merits of the next-generation network are colored by the moving nature of the human activities and the explosive growth in information technology. The future next-generation network should provide global coverage and mixed media services. Terrestrial networks have limited coverage and may be economically infeasible while satellite systems play an excellent role in global coverage to provide wireless connection everywhere. The future next-generation network should be an integrated terrestrial/satellite network. Handling the teletraffic load in this multilayer network needs intelligent protocol architecture.

A teletraffic model was established for a multi-layer terrestrial/satellite global communication network. The teletraffic performance of the structure was analyzed and inspected for nominal system parameters. The architecture is flexible to accommodate different traffic intensities generated by different user categories. Varieties of handoff priority schemes were proposed in order to improve the performance of the system. The presented analysis will help network designers to implement the future global network based on sound concepts.

7.2 Future Work

Software radio is a revolutionary concept to face the problem of different standards for mobile networks around the world. Instead of building separate hardware for different systems, a single general-purpose platform is used to perform these different functions by simply running a different program. In other words, a software radio is a wireless communications device in which some or all of the physical layer functions are implemented in software.

The flexibility provided by the software implementation enables a single device to inter-operate with other devices using different wireless physical technology, by simply invoking the appropriate software. This would not only enable seamless anytime, anywhere connectivity, but also provide users the flexibility of choosing from the available connectivity options the best suit price/performance requirements.

For example, a generic receiver can inter-operate with multiple different cellular systems by running different programs. In other words, software radios would enable travelers to overcome the difficulties in going through areas that use different standards. As you go into an area that uses a different cellular telephone, the infrastructure could notify your phone about the local requirements, and the phone would automatically reconfigure for use in that area. This allows different regions to adopt the standards that best suit their environment.

In the near future, there is no doubt that software radios can freely mix analog and digital technology to achieve optimum performance, cost and reliability. The "future proof" structure of software radio structure would enable consumers to upgrade their phones with new applications–much like purchasing new programs for their computers.

List of Figures

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