Chapter 2

Radio Resource Management in GSM and CDMA

2.1 Introduction

This chapter discusses the parameters of Global System for Mobile Communications (GSM) and Code Division Multiple Access (CDMA). Radio Resource Management strategies in GSM and CDMA are also discussed.

For GSM, implementation of Fixed Channel Allocation (FCA) is discussed in [3]. A pathloss model used for this system is referred from [2] which is used for implementation of FCA. The performance improvement in call dropping probability is achieved by handling handoff calls through prioritizing [39]. For evaluation of the performance of FCA and DCA, the blocking and dropping probabilities are calculated for reservation of channels for handoff calls.

In case of CDMA, there is steady growth in number of mobile users. Cell size is telescoped to swell system capacity. Handoff rate is increased by reduction in the cell size. To overcome these problems, after studying different schemes a new scheme, mutual frequency assignment (MFA) is proposed. Efficient use of radio resources is very important, utilization of all resources have to be maximized. This is achieved using MFA.
2.2  Global System for Mobile Communication (GSM)

2.2.1 GSM Network Architecture Elements

The GSM network architecture is shown in Figure 2.1.

![GSM System Architecture](image)

**Figure 2.1: Simplified GSM System Architecture**

It is grouped into four main areas. [40]

- Mobile station (MS)
- Base-station subsystem (BSS)
- Network and Switching Subsystem (NSS)
- Operation and Support Subsystem (OSS)

2.2.2 RADIO Resource Management (RRM) in GSM

RRM involves strategies and algorithms for controlling parameters such as transmit power, channel allocation, data rates, handover criteria, modulation scheme and error coding scheme. The objective is to utilize the limited radio spectrum resources and radio network infrastructure as efficiently as possible.

RRM concerns multi-user and multi-cell network capacity issues, rather than point-to-point channel capacity. Efficient dynamic RRM schemes may increase the
system capacity in order of magnitude, which is considerably more effective than what is possible by introducing advanced channel coding and source coding schemes.

RRM is classified into Static RRM, Inter-Cell RRM and Dynamic RRM, as shown in Figure 2.2. RRM is especially important in systems limited by co-channel interference rather than by noise.

![Diagram showing RRM and its types]

Figure 2.2: Types of RRM

**Protocol Description**

The channel assignment schemes in general can be classified into three strategies:

- **Fixed Channel assignment (FCA)**
- **Dynamic Channel Assignment (DCA)**
- **Hybrid Channel Assignment (HCA)**

**Fixed Channel Assignment (FCA):** In FCA each cell is given predetermined set of voice channel. If all channels are occupied then call is blocked in this system. There are several variations in FCA. One of it is borrowing strategy in
which a cell can borrow channels from neighboring cell which is supervised by Mobile Switching Center (MSC).

- **Dynamic Channel Assignment (DCA):** These are more efficient ways of channel allocation in which voice channels are not allocated to cell permanently. For every call request from user equipment (UE), base station requests the channel from MSC. The channel is allocated following an algorithm which accounts likelihood of future blocking within the cell. It requires the MSC to collect real time data on channel occupancy, traffic distribution and Radio Signal Strength Indications (RSSI).

### 2.2.3 Analytical Model

A system with multiple cells is considered and all cells are assumed to have homogeneous traffic. The cell parameters such as number of channels and TDMA frame cell size is considered to be same for all cells. Each of these cells has $S$ channels. The channels holding time has an exponential distribution with mean duration. Both originating and handoff calls are generated in a cell according to Poisson’s process, with mean rate $\lambda_o$ and $\lambda_h$ respectively. The system model is as shown in Figure 2.3.

![Figure 2.3: A generic system Model](image)

As system is assumed to have all cells as homogenous, focus is given on one cell only. An analytical model for single cell was developed considering both types of calls [5]. Newly generated calls in cell of interest are labeled as originating calls. A handoff request will be generated when a channel holding mobile station approaches the cell of
interest from its neighboring cell with signal strength below the handoff threshold. In this model all $S$ channels are shared by both originating and handoff request calls. The cell handles a handoff request exactly in the same way as an originating call. Both kinds of requests are blocked if no free channel is available.

With the blocked call clear (BCC) policy, the cell behavior can be described as $(S+I)$ states Markov process. Each state is labeled by an integer $I$ ($I = 0, 1, 2...S$) and it represents the number of channels in use. The state transition diagram is shown in Figure 2.4. The system model is modeled as M/M/s/s queuing model.

Let $p$ be the probability that the system is in state $I$. The probabilities $p(i)$ can be determined in the usual way from birth-death processes. From Figure 2.4 the state equilibrium is written as in equation (2.1).

$$p(i) = \frac{\lambda_o + \lambda_h}{i\mu} \cdot p(i-1) \quad 0 \leq i \leq S$$  

Using this equation recursively, along with the normalization condition.

$$\sum_{i=0}^{i} p(i) = 1$$  

The steady state probability $p(i)$ is expressed by equation 2.3.

$$p(i) = \frac{\lambda_o + \lambda_h}{i\mu} \cdot p(0) \quad 0 \leq i \leq S$$  

Where $p(0)$ is given as,
\[ p(0) = \frac{1}{\sum_{i=0}^{s} \frac{(\lambda_0 + \lambda_H)^i}{i!\mu^i}} \]  

(2.4)

The blocking probability \( p_b \) for an originating call is given by,

\[ p_b = p(S) = \frac{(\lambda_0 + \lambda_H)^i}{\sum_{i=0}^{s} \frac{(\lambda_0 + \lambda_H)^i}{i!\mu^i}} \]  

(2.5)

The dropping probability is, \( p_d = p_b \), where \( p_b \) is calculated by considering the handoff calls generation rate only (\( \lambda_H \)).

### 2.2.4 Simulation Model

#### Simulation Formation

The simulation model is designed employing a top-down approach using MATLAB. The hierarchical structure of network scenarios, users, and processes are provided as comprehensive developmental environment to model the network. The Discrete Event simulation method is modeled for all networks under consideration. Simulation model that is made for analysis is as follows.

The simulated system consists of 25 cells each of which has four neighboring cells as shown in figure 2.5.

![Simulated Wireless Network](image-url)  

Figure 2.5: Simulated Wireless Network
It is assumed that the top cells (Cell 21, 22, 23, 24 and 25) and the bottom cells (Cell 1, 2, 3, 4 and 5) are connected. It means that if a user comes out of 21 from top, he will come into cell 1. Analogously, it is assumed that the cells (cell 1, 6, 11, 16 and 21) and right cells (cell 5, 10, 15, 20 and 25) are connected too.

Assume the base station of each cell is at the center of square. The handoff threshold can be set at any distance between cell-center to receive-threshold. The area between handoff-threshold and receive-threshold is called handoff area. (shaded area of Figure 2.6).

The user movement and distribution within the cell pattern is described as follows. When a new call request is generated, the location of the mobile users is random variable, and moving direction is chosen from uniform distribution on the interval as shown in table 2.1.

<table>
<thead>
<tr>
<th>Random Number (0-1)</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.25</td>
<td>Target cell is North cell</td>
</tr>
<tr>
<td>0.25-0.5</td>
<td>Target cell is East cell</td>
</tr>
<tr>
<td>0.5-0.75</td>
<td>Target cell is South cell</td>
</tr>
<tr>
<td>0.75-1</td>
<td>Target cell is West cell</td>
</tr>
</tbody>
</table>

The moving speed is uniformly distributed between 8 and 25 m/sec. The user’s location and RSS is monitored at every second.
Radio Propagation Model

Radio propagation is influenced by the path loss depending on the distance, shadowing, and multipath fading.

The relationship between the transmitted power and received power can be expressed as below. [2]

\[ P(r) = 10^{\frac{\xi}{10}}, r^{-\alpha}P_o \]  \hspace{1cm} (2.6)

where, \( P(r) \) is the received power; \( P_o \) is the transmitted power, \( r \) is the distance from the base station to mobile, \( \xi \) in decibels has a normal distribution with zero mean and \( \alpha \) is attenuation factor.

Following assumptions are made for simulation

1. Each cell has \( C=30 \) channels.
2. Cell radius = 2000 m
3. Arrival of new calls initiating in each cell forms a Poisson’s process with rate \( \lambda \).
4. Each call requires only one channel for service.

As shown in the flowchart (Figure 2.7), initially call request is generated in the cell, once a new call is admitted into the network, lifetime of this call is selected according to its distribution and then total number of new calls is estimated. If channels are accessible new call is accepted otherwise it is blocked.

Once the call is accepted the parameters of call are updated and signal strength is checked, if signal strength is less than handoff threshold, at the same time if channel is available, handoff request is accepted otherwise it is blocked. Thus new blocking probability and handoff blocking probability is evaluated.

2.3 Code Division Multiple Access (CDMA)

CDMA works on the principle of spread spectrum. With the help of a CODE, data signal is spread like a noise- like signal which is unable to detect by others. It provides security as well as noise reduction.
Launched commercially in 1995, the first CDMA network provided roughly ten times more capacity than analog networks, and far more than TDMA or GSM. CDMA has increased, cellular communication’s security, and efficiency. It means that the carrier can serve more subscribers. Also it has low power requirements and little cell-to-cell coordination needed by operators.

![Flowchart for call Threshold Scheme](image-url)

Figure 2.7: Flowchart for call Threshold Scheme
2.3.1 Adaptive Radio Resource Management in Hierarchical Cell Structure (HCS)

CDMA system provides large capacity compared with other systems [9]. The most commonly used methods for increasing capacity are sectorization and microcell concept, but disadvantage is increased number of handoffs. So, hierarchical cell structure has been proposed in order to overcome these problems.

In hierarchical cellular system, because mobile users select appropriate cell layer in accordance with their speed, increase in handoff by fast users, who select macrocell with large cell size, is solved and capacity is increased by shrinking cell size for low speed users [44]. Each layer uses its own radio frequency. In these conditions, spectrum allocation is very important issue, because frequency spectrum is a limited resource. Since available spectrum is limited in HCS (hierarchical cellular system) load balancing or resource sharing is needed in order to prevent each layer from being overloaded.

In order to adapt the changes of traffic, it is necessary to consider adaptive resource management. Load of each layer in HCS can be balanced by controlling threshold velocity by which appropriate cell layer is selected [8]. A resource which can be shared between layers in CDMA based HCS is only Frequency Assignment (FA).

Load of each layer is balanced by changing threshold velocity according to traffic condition, but when several adjacent microcells are overloaded in rush-hour, overload of those cells cannot be solved because macrocell does not have enough resources to serve all overflowed mobile users. In order to overcome this problem, Frequency Borrowing Resource Allocation (FBRA) scheme is used, but if macrocell does not have enough FA to support overloaded microcell, this problem cannot be solved [10].

2.3.2 Scheme 1: Static Radio Resource Management (Passive)

In this system, a large number of mobile stations are traversing randomly in the coverage area of the cell, where two classes of fast and slow mobile stations are considered. Further it is assumed that a mobile station does not change its speed class
(during a call). The operation of the system is described in Figure 2.8.

Let,

- \( im \) = Number of microcell, (where \( im= 1, 2... \ N. \))
- \( c_o \) = Number channels allocated to macrocells
- \( c_{im} \) = Number of channels allocated to \( im^{th} \) microcell.

- A slow mobile station generates a new call and it is directed first to the camped-on microcell. If the number of traffic channels in the microcell \( im \) is identical to \( c_{im} \) this new call may be overflowed to that overlaid macrocell. The overflowed new call will be accepted by the macrocell if the number of traffic channels occupied in the macrocell is less than \( c_o \), otherwise the call will be blocked.

- A fast mobile station generates new call and is directed first to the camped-on macrocell. If the number of traffic channels occupied in the macrocells is equal to \( c_o \), this new call may be overflowed to the overlaid microcell which provides radio coverage to the mobile station. This new call will be accepted by the microcell if the number of traffic channels occupied in the microcell \( im \) is less than \( c_{im} \), otherwise the call will be blocked.

Figure 2.8: Hierarchical Cell: Flow of new and handoff traffic and their Overflow.
• A handoff request of a slow mobile station is directed first to the target microcell independent of whether the current serving cell is a neighboring microcell or an overlaying macrocell. If all traffic channels in the target microcell are busy.

• A handoff request of a fast mobile station is first directed to the target macrocell independent of whether the current serving cell is a neighboring macrocell or a neighboring microcell. If all traffic channels in the target macrocell are busy, the handoff request may be overflowed to the neighboring microcell, which will provide radio coverage for the mobile station. The overflowed handoff request will be served by the microcell if there is any idle traffic channel; otherwise, the handoff request will fail and the call will be forced to terminate (dropped).

Model Description

In this section, system parameters are defined and system model is described. Low and high mobility mobile stations are two populations of mobile stations. The optimum spectral efficiency through frequency reuse can be achieved if the traffic of low-mobility mobile stations is carried by microcell channels and the traffic of high-mobility mobile stations is carried by macrocell channels, respectively.

The total arriving traffic to the area \( \Omega \) is denoted by \( \lambda \). The area under consideration has one overlaying macrocell and \( N \) microcells, \( im = 1, 2, ..., N \). (Figure 2.8). For simplicity, it is assumed that the microcells are all identical circles with radius \( r_i \) and the macrocells are circles with radius \( r_0 \). New traffic solely generated by fast mobile stations is according to a Poisson process with parameter \( \lambda_{f_0} \). New traffic solely generated by slow mobile stations in microcell \( im \), \( (im = 1, 2, ..., N) \), is according to a Poisson process with parameter \( \lambda_{im} \). The average speed of the slow and fast mobile subscribers is considered to be \( V_s \) and \( V_f \) respectively.

The calls arriving from fast mobile subscribers have overloaded call duration according to a negative exponential distribution with parameter \( \mu \). The unencumbered call duration is the amount of time that the call would remain in progress without forced
termination.

It is assumed that the cell’s dwell time, that is, the time spent by a mobile station in a cell is a random variable approximated by a negative exponential probability density function (pdf) [44]. For macrocells, the parameters of the exponential pdf for fast and slow mobile station are denoted by $\eta_0$ and $\eta'_0$ respectively. Similarly, for microcells, the parameters are designated by $\eta_1$ and $\eta'_1$ for slow and fast mobile stations, respectively.

With the above assumptions, the channel occupancy time, that is, the time spent in a cell by a mobile station being involved in a call, will follow negative exponential distribution.

For a macrocell, the handoff rate of calls from slow and fast mobile stations is denoted by $P_{ho}'$ and $P_{ho}$ respectively, and for a microcell for slow and fast mobile stations by $P_{ho1}'$ and $P_{ho1}$ respectively.

The handoff traffic from slow and fast mobile stations in microcell and macrocell is denoted as follows.

- $\lambda_{sh1} = \text{Rate of slow mobile station handoff traffic in a microcell.}$
- $\lambda_{sh0} = \text{Rate of slow mobile station handoff traffic in a macrocell.}$
- $\lambda_{fh1} = \text{Rate of fast mobile station handoff traffic in a microcell}$
- $\lambda_{fh0} = \text{Rate of fast mobile station handoff traffic in a macrocell}$

**Performance Analysis**

In this section analytical results for the system are presented. During analysis fluid mobility model is considered. Derivation of slow and fast mobile station’s cell dwell time in macrocell and microcells is taken into account [44]. Overflow traffic is treated as Poisson’s distribution and the take-back traffic is delayed until the cell boundary
crossing.

1. In order to obtain the mean channel occupancy time, the mean cell dwell time, or their inverse, the cell boundary crossing parameters need to be calculated. Using a fluid flow mobility model, the cell boundary crossing can be derived as follows for a macrocell [9][10].

\[ \eta_0 = \frac{2V_f}{\pi r_0} \]  
\[ \eta'_0 = \frac{2V_s}{\pi r_0} \]

Where,

\( \eta_0 \) = Exponential pdf for fast MS in macrocell

\( \eta'_0 \) = Exponential pdf for slow MS in macrocell

\( V_s \) = Average speed of slow mobile subscribers

\( V_f \) = Average speed of fast mobile subscribers

2. The handoff probability of calls of slow and fast mobile stations in a macrocell is given by

\[ P_{ho} = \frac{\eta_0}{\mu + \eta_0} \]  
\[ P'_{ho} = \frac{\eta'_0}{\mu + \eta'_0} \]

3. The session duration of slow and fast mobile stations in macrocell is given by,

\[ \frac{1}{\mu_0} = \frac{1}{\mu + \eta_0} \]  
\[ \frac{1}{\mu'_0} = \frac{1}{\mu + \eta'_0} \]
4. Correspondingly, in a microcell, it can be written as,

\[ \eta_i = \frac{2V_s}{\pi r_i} \]  

\[ \eta_i = \frac{2V_f}{\pi r_i} = \eta_f = \frac{V_f}{V_s} \]  

5. The handoff probability of calls for slow and fast mobile stations in a microcell is calculated as,

\[ P_{hi} = \frac{\eta_i}{\mu + \eta_i} \]  

\[ P_{fi} = \frac{\eta_f}{\mu + \eta_f} \]  

6. The session duration of slow and fast mobile stations in a microcell is given by,

\[ \frac{1}{\mu} = \frac{1}{\mu + \eta_i} \]  

\[ \frac{1}{\mu_f} = \frac{1}{\mu + \eta_f} \]  

7. Estimates for take-back probabilities are as follows

\[ \zeta_s = P_{hi} \]  

\[ \zeta_f = 0 \]  

Where,

\[ \zeta_s = \text{Take-back probability from macrocell (moving slow MS back to microcells)}. \]  

\[ \zeta_f = \text{Take-back probability from microcell (moving fast MS back to macrocells)}. \]
Performance Measures

1. The traffic rate to microcells includes the rate of new arrivals $\lambda_{s1}(1 - P_{bl})$ and the rate of accepted handoff traffic $\lambda_{shl}(1 - P_{bl})$ for slow mobile stations and overflow of new and accepted handoff calls of fast mobile stations from a macrocell, that is, $\lambda_{fh0}P_{bo}(1 - P_{bi})$.

2. The aggregate traffic rate into a microcell due to slow mobile stations is as follow:

$$\hat{\lambda}_{s1} = \lambda_{s1} + \lambda_{sh1} + \lambda_{sb1}$$

(2.21)

Where, the take-back traffic rate component is given as

$$\lambda_{sb1} = (\lambda_{s1} + \lambda_{sh1} + \lambda_{sb1})P_{si}(1 - P_{so})\varsigma$$

(2.22)

3. The aggregate traffic rate into a microcell due to fast mobile stations is given as

$$\hat{\lambda}_{s1} = \frac{1}{N} \left( \lambda_{s0} + \lambda_{sh0} + \lambda_{sb0} \right)P_{so} + \lambda_{fh1}$$

(2.23)

4. The generation rate of slow mobile station’s handoff traffic in a microcell is as follows:

$$\lambda_{shl} = P_{bl}(\lambda_{s1} + \lambda_{sh1} + \lambda_{sb1})(1 - P_{bl})$$

(2.24)

5. The generation rate of fast mobile stations’ handoff traffic in a microcell is as follows:

$$\lambda_{fh1} = P_{h1} \left\{ \frac{1}{N} \left[ \lambda_{fo} + \lambda_{fho} + \lambda_{fh0} \right] P_{bo}(1 - P_{bi}) + \lambda_{fh1}(1 - P_{bi}) + \lambda_{fh1}(1 - P_{bi}) \right\}$$

(2.25)

6. The aggregate traffic rate due to fast mobile stations into a macrocell is as follows:

$$\lambda_{fa} = \lambda_{fo} + \lambda_{fho} + \lambda_{fh0}$$

(2.26)
Where, the take-back traffic rate component is given as:

\[
\lambda_{fbo} = (\lambda_{f0} + \lambda_{sh0} + \lambda_{b0})P_{bo}(1 - P_{b0})\zeta_f
\]  

(2.27)

7. The aggregate traffic rate due to slow mobile stations into a macrocell is given as,

\[
\dot{\lambda}_{s0} = N(\lambda_{s1} + \lambda_{sh1} + \lambda_{sbo1})P_{s1} + \dot{\lambda}_{sh0}
\]  

(2.28)

8. The generation rate of fast mobile station’s handoff traffic in a macrocell is as follows:

\[
\lambda_{fbo} = P_{f0}\left(\lambda_{f0} + \lambda_{fbo} + \lambda_{bo}\right)(1 - P_{b0})
\]  

(2.29)

9. The generation rate of slow mobile station’s handoff traffic in a macrocell is as follows:

\[
\dot{\lambda}_{sbo} = P_{s0}\left\{N(\lambda_{s1} + \lambda_{sh1} + \lambda_{sbo1})P_{s1}(1 - P_{b0}) + \dot{\lambda}_{sh0}(1 - P_{b0})\right\}
\]  

(2.30)

From above equations, it is noted that probability of handoff failure is the same as the probability of blocking of new calls since there is no prioritization of handoff traffic. The probability of call blocking is given by the Erlang loss formula because it does not depend on the distribution of the session time. Invoking this important property, we can use \(\lambda_{01}/\mu_0 + \dot{\lambda}_{01}/\mu'_{01}\) and \(\lambda_{11}/\mu_{1} + \dot{\lambda}_{11}/\mu'_{1}\) as the offered load to macrocell and microcell, respectively, and for \(im=0, 1\), call blocking probability can be written as,

\[
P_{bin} = \frac{\left(\frac{\lambda_{im} + \dot{\lambda}_{im}}{\mu_{im}}\right)^{c_{im}}}{c_{im}!} \frac{\left(\frac{\lambda_{im} + \dot{\lambda}_{im}}{\mu_{im}}\right)^{j}}{j!}
\]  

(2.31)

If,

\[P_{f0} = \text{the probability of call loss for fast mobile station}\]
\[ P_{fl} = \text{the probability of call loss for slow mobile station,} \]
then, the probability of of call loss for fast or slow mobile stations is given by
\[ P_{fo} = P_{fl} = P_{lo}P_{bo} \quad (2.32) \]

If no take-back is considered, the probability of call dropping for calls in progress from fast mobile stations is given as follows:
\[ P_{d0} = P_{k0}P_{bo}P_{b1} \quad (2.33) \]

2.3.3. Scheme 2: Variable Threshold Velocity Scheme (VTVS)

The performance parameters of traffic capacity of the system are very important.

![Diagram](image)

Figure 2.9: Variable threshold velocity scheme

The traffic capacity is fundamentally determined by the teletraffic which is carried by the system [8]. However, the definition of carried traffic only makes sense if Quality of Service (QoS) parameters are taken into consideration. The different kinds of handovers as well as their triggering events are represented in Figure 2.9.
The basic principle of the velocity control threshold ($v_{th}$) is explained in figure 2.10. By dynamically adapting $v_{th}$, the amount of traffic that is sent to the respective layers can be controlled. In figure 2.10, exclusively overall loss probability in the macro-layer is considered [9].

2.3.4. Scheme 3: Frequency Borrowing Resource Allocation

In order to solve hot spot problem occurred in rush-hour, FBRA (Frequency Borrowing Resource Allocation) is proposed. In this scheme, FA’s in macrocell are classified into two groups: dedicated FA and mutual FA [10]. Dedicated FA’s are only used in a macrocell and mutual FAs are ordinarily used in a macrocell but used in microcell for rush-hour. One FA in macrocell can serve up to 36 users and one FA in microcell can serve up to 30 users.

Disadvantage of this scheme is that this scheme is effective when fast users can be served by only dedicated FA in macrocell; it means that FBRA cannot unfortunately be applied when the number of user in macrocell is more than pole capacity of dedicated FA in macrocell.

2.3.5 Scheme 4: Proposed Scheme (Mutual Frequency Assignment)

The proposed scheme can solve two problems. Flowchart of proposed scheme is shown in figure 2.11.
Figure 2.11: Flowchart of MFA

START

Microcells are busy

Y

Microcells can lend MFA

Y

Microcells has used MFA

Y

$\nu_{th} = \nu_{th} - \Delta v_1$
Microcell use MFA

Y

$\nu_{th} = \nu_{th} - \Delta v_2$
Microcell use MFA

N

Microcells are not busy

Y

$\nu_{th} = \nu_{th} + \Delta v_{1/2}$
Macrocell uses MFA

34
First, when several adjacent microcells are overloaded in rush-hour, over-loads of those cells can be solved. Second, when more fast users of all dedicated FA’s request service in macrocell, load of macrocell is decreased by increasing $v_h$ and then microcells use MFA (Mutual Frequency Assignment). In this case, hand-off between layers occurs and this is called connect-after-break.

When microcells are overloaded, macrocell should lend microcells MFA, like scheme 3. FA’s in macrocell are classified into dedicated FA (DFA) and mutual FA (MFA). When a call is originated, resource in DFA is preferentially assigned and if all resources in DFA are exhausted, resource in MFA is assigned.

If macrocell is not busy (regardless of use of MFA), macrocell decrease its load by increasing $v_h$ and then lends microcells MFA. Also, macrocell can control decrease of load. If macrocell was using MFA, its load is decreased by using $\Delta v_l$ and otherwise, by using $\Delta v_2 (< \Delta v_1)$.

Consequently, the resource shortage in microcell is solved by increasing the number of resource and the resource shortage in macrocell is solved by decreasing traffics in macrocell [46].

Conceptual operation of each scheme, when all calls in macrocells are assigned in only DFA is described in Figure 2.12. Utilization of resource is given by $U_R$ and defined as,

$$U_R = \text{the number of user / pole capacity of cell}$$

In scheme 1, $U_R$ of microcells will increase with load of microcells and in scheme 2, for a little while, load of microcell will be stabilized by increasing $v_h$, but load of macrocell will increase and thus be rapidly saturated as shown in Fig 2.13. In this case, since MFA in macrocell is not used, scheme 3 and scheme 4 show superior performance.
The conceptual operation of each scheme is described in Figure 2.13 when some calls in macrocell are assigned in MFA. Operations of scheme 1 and scheme 2 will be similar to the case of Fig 2.12, but scheme 3 will show worst performance since macrocell cannot lend microcell MFA. In scheme 4, by frequency borrowing and increase of \( u_{th} \), load of macrocell will be decreased and \( U_R \) of microcell will be abruptly decreased and, after this, increased right away again.

Figure 2.12: Output of each scheme when MFA is not used in macrocell

Figure 2.13: Operation of each scheme when MFA is used.
2.3.6 Simulation Environment

Each layer uses two FAs. One of FA in macrocell is DFA and another is MFA. The simulation parameters for MFA are shown in Table 2.2

<table>
<thead>
<tr>
<th>Sr No.</th>
<th>Parameters</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No. of macrocells</td>
<td>01</td>
</tr>
<tr>
<td>2</td>
<td>No. of microcells</td>
<td>06</td>
</tr>
<tr>
<td>4</td>
<td>Neighboring macrocells</td>
<td>05</td>
</tr>
<tr>
<td>5</td>
<td>Neighboring microcells</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>Radius of microcell</td>
<td>500 m</td>
</tr>
<tr>
<td>7</td>
<td>Radius of macrocell</td>
<td>1000 m</td>
</tr>
<tr>
<td>7</td>
<td>Velocity of mobile user</td>
<td>0 km/h to 60 km/h</td>
</tr>
<tr>
<td>8</td>
<td>No. of calls in one FA of macrocell</td>
<td>36</td>
</tr>
<tr>
<td>9</td>
<td>No. of calls in one FA of microcell</td>
<td>30</td>
</tr>
</tbody>
</table>

The number of user per FA in microcell is smaller than that in macrocell since neighboring macrocell can use the same FA as that in microcell and transmission power in macrocell is higher than that in microcell. Both speed and direction of each user are constant during call duration time or a considered macrocell dwell time. Load of each layer varies with time. It is expected that load of microcell is small when macrocell is overloaded.

2.4. Simulation Results

GSM

The validation of simulation model for GSM is performed by writing a MATLAB code for analytical solution presented in section 2.2.3. The simulation is carried out for generic model and the result of analytical solution and simulation is presented in figure
From this figure it is concluded that the analysis and simulation results matches with each other, hence it is stated that the simulation model is validated. Hereafter, the same simulation model will be used to investigate the radio resource management in GSM. Table 2.3 presents comparison of blocking probability for FCA and DCA. For DCA it is less as compared to FCA for traffic ranging from $10^0$ to $10^{-3}$ Erlangs.

![Figure 2.14: Verification and Validation](image)

Table 2.3: Comparison of blocking probability for FCA and DCA

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<thead>
<tr>
<th>Traffic (Erlang)</th>
<th>Blocking Probabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FCA</td>
</tr>
<tr>
<td>$10^3$</td>
<td>0</td>
</tr>
<tr>
<td>$10^2$</td>
<td>0.00066</td>
</tr>
<tr>
<td>$10^1$</td>
<td>0.00157</td>
</tr>
<tr>
<td>$10^0$</td>
<td>0.00244</td>
</tr>
</tbody>
</table>
As a first experiment on FCA channel assignment policy with handoff reservation of 5%, 10% and 15% are studied and figure 2.15 depicts the blocking probability graph. From figure 2.15 and table 2.4, it is observed that the blocking probability increases with increasing channel reservation for handoff. This is obvious result, since less number of channels are available for new calls generated in a cell.

![Blocking Probability FCA HOR](image)

**Figure 2.15: Blocking probability of FCA HOR**

<table>
<thead>
<tr>
<th>Traffic</th>
<th>Blocking Probability HOR-5</th>
<th>Blocking Probability HOR-10</th>
<th>Blocking Probability HOR-15</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^3$</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$10^2$</td>
<td>0.00046</td>
<td>0.00056</td>
<td>0.00066</td>
</tr>
<tr>
<td>$10^1$</td>
<td>0.00117</td>
<td>0.00137</td>
<td>0.00157</td>
</tr>
<tr>
<td>$10^0$</td>
<td>0.00184</td>
<td>0.00224</td>
<td>0.00244</td>
</tr>
</tbody>
</table>
The second performance metric for RRM assessment is dropping probability. Figure 2.16 shows the dropping probability graph for FCA. It is observed that for 15% reservation the dropping probability is lowest as compared to 10% and 5% reservation. (Table 2.5)

Figure 2.16: Call Arrival VS Dropping probability of FCA

Further investigation in GSM system is performed for radio resource management in a dynamic channel assignment. The simulation results for DCA with handoff channel reservation are shown in figure 2.17 and 2.18; for blocking and dropping probabilities respectively. From figure 2.17 it is observed that the performance of GSM from DCA is equivalent to FCA but there is some improvement in the blocking probability.
Table 2.5: Dropping probability of FCA

<table>
<thead>
<tr>
<th>Call Arrival Rate</th>
<th>Dropping Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HOR-5</td>
</tr>
<tr>
<td>$10^{-3}$</td>
<td>0.0000001675</td>
</tr>
<tr>
<td>$10^{-2}$</td>
<td>0.000001135</td>
</tr>
<tr>
<td>$10^{-1}$</td>
<td>0.000008465</td>
</tr>
<tr>
<td>$10^{0}$</td>
<td>0.0006885</td>
</tr>
</tbody>
</table>

Figure 2.17: Blocking probability of DCA HOR

Table 2.6: Blocking probability of DCA HOR

<table>
<thead>
<tr>
<th>Call Arrival Rate</th>
<th>Blocking Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HOR-5</td>
</tr>
<tr>
<td>$10^{-3}$</td>
<td>0</td>
</tr>
<tr>
<td>$10^{-2}$</td>
<td>0.00034</td>
</tr>
<tr>
<td>$10^{-1}$</td>
<td>0.0009</td>
</tr>
<tr>
<td>$10^{0}$</td>
<td>0.0016</td>
</tr>
</tbody>
</table>

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From figure 2.18, it is observed that the dropping probability performance of DCA is poor than FCA at higher traffic. (Table 2.7) This degradation of dropping probability is due to non availability of channels in the adjoining cells. This situation arises due to the fact that in DCA, the channel allocation has to satisfy the adjacent channel requirements.

![Dropping Probability Vs Traffic for DCA](image)

**Figure 2.18:** Dropping probability of DCA HOR

**Table 2.7:** Dropping probability vs. traffic

<table>
<thead>
<tr>
<th>Traffic</th>
<th>Dropping Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HOR-5</td>
</tr>
<tr>
<td>$10^3$</td>
<td>0.0000001575</td>
</tr>
<tr>
<td>$10^2$</td>
<td>0.0000000735</td>
</tr>
<tr>
<td>$10^1$</td>
<td>0.0000003465</td>
</tr>
<tr>
<td>$10^0$</td>
<td>0.0004885</td>
</tr>
</tbody>
</table>
CDMA

To study the RRM in CDMA, four different RRM policies are under consideration. There is overlay-underlay mapping of the terrain to improve the performance of the cellular system. Figure 2.19 and table 2.8 shows the results of the simulation.

![Figure 2.19: Blocking probability of Macro and Micro cell vs. Traffic](image)

**Scheme1 (S-1):** Radio Resource Management using teletraffic modeling (Passive)

**Scheme 2 (S-2):** Variable Threshold Velocity Scheme. (VTVS)

**Scheme 3 (S-3):** Frequency Borrowing Resource Allocation. (FBRA)

**Scheme 4 (S-4):** Mutual Frequency Assignment (MFA)

From figure 2.19, it is observed that the blocking probability for ‘macrocell’ is less as compared to ‘microcell’. This is due to the fact that there will be less number of users whose velocity of movement will be higher than the slow moving users. For the comparison purpose, conventional RRM (Passive) is simulated and is compared with three RRM variants, called VTVS, FBRA and MFA. It is also observed that MFA outperforms all other RRM’s. Table 2.8 lists the numerical values of the blocking
probability of Macrocell and microcell.

Table 2.8: Blocking Probability of Macrocell and Microcell

<table>
<thead>
<tr>
<th>Call Arrival Rate</th>
<th>Blocking Probability of Macrocell</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RRM, Passive (S-1)</td>
<td>VTVS (S-2)</td>
<td>FBRA (S-3)</td>
<td>MFA (S-4)</td>
</tr>
<tr>
<td>$10^{-3}$</td>
<td>0.000000018</td>
<td>0.00000016</td>
<td>0.00000014</td>
<td>0.00000012</td>
</tr>
<tr>
<td>$10^{-2}$</td>
<td>0.00000015</td>
<td>0.00000075</td>
<td>0.00000045</td>
<td>0.00000026</td>
</tr>
<tr>
<td>$10^{-1}$</td>
<td>0.000021</td>
<td>0.0000081</td>
<td>0.0000037</td>
<td>0.0000014</td>
</tr>
<tr>
<td>$10^{0}$</td>
<td>0.0013</td>
<td>0.00077</td>
<td>0.00034</td>
<td>0.00015</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Call Arrival Rate</th>
<th>Blocking Probability of Microcell</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RRM, Passive (S-1)</td>
<td>VTVS (S-2)</td>
<td>FBRA (S-3)</td>
<td>MFA (S-4)</td>
</tr>
<tr>
<td>$10^{-3}$</td>
<td>0.0000032</td>
<td>0.0000027</td>
<td>0.0000018</td>
<td>0.0000011</td>
</tr>
<tr>
<td>$10^{-2}$</td>
<td>0.000068</td>
<td>0.000037</td>
<td>0.000017</td>
<td>0.0000074</td>
</tr>
<tr>
<td>$10^{-1}$</td>
<td>0.0013</td>
<td>0.00061</td>
<td>0.00021</td>
<td>0.000073</td>
</tr>
<tr>
<td>$10^{0}$</td>
<td>0.1</td>
<td>0.048</td>
<td>0.021</td>
<td>0.008</td>
</tr>
</tbody>
</table>

Figure 2.20: System’s overall Dropping Probability
Figure 2.20 shows the results of systems overall dropping probability in case of all the RRM’s as mentioned earlier. It is observed that MFA results in better performance than the other three RRM’s (table 2.9).

Table 2.9: Dropping probability of overall system.

<table>
<thead>
<tr>
<th>Traffic (Erlang)</th>
<th>RRM, Passive (S-1)</th>
<th>VTVS (S-2)</th>
<th>FBRA (S-3)</th>
<th>MFA (S-4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-3}$</td>
<td>0.000014</td>
<td>0.0000051</td>
<td>0.000002</td>
<td>0.0000005</td>
</tr>
<tr>
<td>$10^{-2}$</td>
<td>0.000041</td>
<td>0.0000102</td>
<td>0.0000038</td>
<td>0.0000065</td>
</tr>
<tr>
<td>$10^{-1}$</td>
<td>0.00012</td>
<td>0.000032</td>
<td>0.000008</td>
<td>0.0000088</td>
</tr>
<tr>
<td>$10^{0}$</td>
<td>0.0011</td>
<td>0.0003</td>
<td>0.000061</td>
<td>0.000022</td>
</tr>
</tbody>
</table>

It is also observed that the variation of dropping probability with respect to change in traffic is very low as compared to other three schemes. This is due to the fact that the velocity threshold is dynamically adjusted in accordance with the traffic conditions.

### 2.5 Conclusion

#### 2.5.1 GSM

1. Performance of FCA and DCA is evaluated. The blocking and dropping probabilities are calculated for reservation of channels for handoff calls. From the analysis and simulation carried out, it can be concluded that dropping probability for HO-reservation of 15% channels is best. The results of simulation and an analytical model indicate that as there is increase in percentage of priority channels, dropping probability reduces.

2. It is necessary to keep both, cochannel interference and adjacent channel interference, under a certain threshold. This is achieved by restricting cells within the required minimum channel reuse distance from a cell that borrows a channel from the central pool, DCA also requires fast real-time signal processing and associated channel database updating.
2.5.2 CDMA

1. A new adaptive radio resource management scheme is proposed in CDMA based hierarchical cell structure i.e. MFA [8] [9]. In this scheme, the resource shortage in microcell is solved by increasing the number of resource and the resource shortage in macrocell is solved by decreasing traffic in macrocell. One of the notable features in the proposed scheme is to increase threshold velocity rather than to decrease threshold velocity when most channels in microcell are busy.

2. Thus, abrupt increase of macrocell load caused by decreasing threshold velocity when microcell is overloaded can be solved. Although the number of handoff is increased in this case, the number of call loss can be decreased since this problem occurs during only rush-hour. In other words, call could be prevented from dropping or blocking although handoff rate is increased slightly. It is revealed that this proposed scheme MFA, considerably improves call dropping, call blocking and utilization of resource.