Chapter 2: Mobile Networks and Channel Allocation

2.1 Introduction

Cellular technology has advanced very quickly. Due to useful features of ubiquitous wireless technology and affordability, it is already within reach and has gained acceptance in the masses. Cellular wireless connectivity supports convergence of the Internet to "anytime, anywhere, and to all devices those are envisioned to be interconnected. To support anytime connectivity puts stringent demand on to the network being available at all times, including congestion. This calls for smart and efficient ways of load distribution. Reasonable and demand based load distribution is a challenge especially due to the high speed multimedia applications for mobile devices. Mobile cellular networkshave to extend the Internet applications and high quality video which may be received from real time streaming source. Anywhere connectivity refers to the expectation that cellular network should deliver the requested services independent of the location and on the move.ITU (international telecommunication union), the body which defines the requirements for each generation of mobile communications system, has been laying standards and service features for the next generation mobile networks.

Various strategies have been employed for the allocation of channel in GSM network. In Fixed Channel Allocation (FCA), channel in permanently allocated to each cell for its exclusive use. FCA could follow a uniform pattern if traffic is uniformly distributed, else number of nominal channels allocated to each cell may be decided based on traffic profile in that cell. Dynamic Channel Allocation (DCA) schemes propose allocation of channels to a central pool and these is no fixed relationship between channels and cells. Central channel pools are assigned dynamically to new calls as they arrive in the system. The main idea of DCA schemes is to evaluate the cost of using each candidate channel and select one with minimum cost. Selection of cost of a channel may depend on future blocking of calls in the vicinity of cell, the frequency of a candidate channel reuse distance channel occupancy distribution blocking, probabilities, type of quality of service requirements, queuing requirements etc. DCA can be adaptive to respond to varying traffic patterns. Hybrid Channels Allocation scheme (HCA) which is a combination of FCA and DCA in which few of channelscanbe allotted centrally for dynamic borrowing. Whenever a new call arrives in a cell and all its nominal channels are busy a channels from dynamic set can be allotted.
2.2 **Evolution of Cellular Technology**

A channel allocation scheme can be modeled to attain a low blocking probability with limited spectrum availability ensuring co-channel and adjacent channel constraint. A theoretical assessment is also available in [2.1] to compute minimum number of channels to be made available to achieve certain blocking probability. There are performance bounds that can be defined for cellular network with different channel allocation constraints. Thus, performance comparison of various schemes could be done by relating to these bounds. Performance bounds can also be analytically modeled. A system of M cells which share common pool of m channels is considered. An asymptotic traffic property (ATP) proposed in [2.2] was found to satisfy traffic models with common Poisson arrival rates and exponential call holding times. The analytical model aims at maximizing the sum of carried traffic over the complete system.

It is considered that signal to MS is transmitted through nearest BS. Any signal received from other BS is treated as noise. Users within a cell access a channel orthogonally and do not cause any interference to each other. Efficiency of any channel reuse scheme will depend on reuse factor. As discussed in [2.3], a reuse factor of ½ would imply that half of the available bandwidth can be used in a cell N and remaining half bandwidth can be allocated to N-1 and N+1 cell. MS, when moving closer to the cell boundary, also receives signal from neighboring cell. Decreasing reuse factor, improves co-channel interference but the loss of bandwidth is much pronounced. Reuse factor also depends on the type of channel whether additive wide Gaussian noise (AWGN) of fading channels.

Performance of channel assignment Algorithm for cellular (i.e. TDMA or FDMA) system can be analyzed using mathematical model. Channel reuse restrictions and variation in traffic intensity have been made basis for the mathematical Hyper graph model in [2.4]. Capacity of cellular system is defined in Erlangs per channel ($r_0$) such that if offered traffic is more than $r_0$, then a fraction of call request must be blocked for any given channel allocation algorithm. For traffic less than $r_0$ call requests will be accepted (assuming sufficiently large number of channels), that for a given channel assignment scheme, amount of traffic carried by a system (defined as a function of offered traffic) will always be less than or equal to proposed mathematical model $T_{H,p}(r)$, which can be computed by linear programming. In (H,p) pair, H is
a hyper graph describing channel reuse restrictions and ‘p’ is a probability vector showing variation of traffic intensity from cell to cell. ‘r’ is offered traffic intensity to a particular cell and measured in Erlang per channel.

Wireless communication system has also been analyzed as per Erlang loss model using hierarchical and composite Markov chain to obtain loss formula for channel failures. Two hierarchical levels for wireless cellular systems with handoff and channel failures have been proposed in [2.5]. Erlang loss model has been made basis for the hierarchical and composite Markov chain to obtain loss formula for a system which has channel failures.

Pure performance model’ (a conservative approach as it ignores failure and recovery of channels and suitable for wire line networks) and ‘Pure availability Model’ (conservative as performance attributes not considered) as proposed in [2.6] fail to meet the expectations. A more realistic “Bobbio and Trivedi” (BT approach) proposed in the paper gives accurate predictions on wireless system performance. Advancements in composite performance and availability analysis have also been included.

Availability and performance of wireless communication networks was analyzed in [2.7] proposes two new channel strategies viz. ‘Locally Optimized Dynamic Assignment’ (LODA) and ‘Borrowing with Directional Channel Locking’ (BDCL). It has been shown that LODA and BDCL outperform schemes ‘Borrowing with Channel Re-ordering’ (BCO) suggested earlier in [2.8].

The CIR is carrier to interference ratio. It is also referred to as carrier-to-noise ratio (CNR or C/N), which is the signal-to-noise ratio (SNR or S/N) of a modulated signal before demodulation. Interfering of unwanted radio transmitters contributing to I may be controlled by radio resource management. N is noise power from other sources, also classified as Additive White Gaussian noise (AWGN). Cellular radio systems are also referred as interference limited systems, i.e. where I dominates over N. This arises in cellular systems where frequency channels are reused in view to achieve high level of efficiency.

The C/N is more relevant in noise limited systems. If both conditions occur, the carrier-to-noise-and-interference ratio, C/(N+I) or CNIR may be used.

Frequency reuse is a mandatory criterion for the cellular network design. Frequency re-
use refers to the use of same frequency or channel in different geographical areas that are adequately separated. Separation ensures that interference among the reused carriers is within acceptable limit. Cells that use same set of cells are called co-channel cells and the minimum distance within which a frequency can be reused is termed as reuse distance. It is considered that in a cellular environment path loss can be up to 40 dB for each 10 km [2.9]. The ratio of received power of two signals C1 and C2 at distances D1 and D2 respectively (from transmitter to receiver) could be termed as:

\[
\frac{C_2}{C_1} = \left(\frac{D_2}{D_1}\right)^{-4}
\]

10 \log \frac{C_2}{C_1} = 40 \log \frac{D_1}{D_2}

In practice, propagation path loss can be shown as

\[
\Delta C = \propto D^{-\gamma}
\]

Or

\[
\Delta C = 10 \log \alpha - 10 \gamma \log D
\]

\(\propto\) is a constant and \(\gamma\) propagation loss factor. Value of \(\gamma\) lies between 2 and 5. Value 2 corresponds to free space loss. In case of carrier to interference ratio for N interfering cells, is given as under:

\[
\frac{C}{I} = \frac{C}{\sum_{i=1}^{N} I_i}
\]

Under the conditions of negligible local noise, an expression giving out carrier to interference ration can be obtained using [2.9] as under:

\[
\frac{C}{I} = \frac{R^{-\gamma}}{\sum_{i=1}^{N} D_i^{-\gamma}}
\]

R is radius of the cell and D is reuse distance. As shown in [2.10], it is presumed that for a satisfactory transmission quality, \(C/I\) better than 17 dB (in case of omni-directional antenna) over 90% of the coverage area, is desired. If we consider all \(D_i\) to be same for all \(i\) and an omni directional antenna, expression 1.6 will reduce to:

\[
\frac{C}{I} = 10 \log_{10} \left(\frac{D}{R}\right)^{\gamma}
\]
For cluster of size 7 (N=6) and $\frac{C}{i} = 17$ dB an $\gamma = 4$ in a general case will yield

$$17 = 10 \log \frac{1}{6} \left( \frac{D}{R} \right)^4$$

i.e. $\frac{D}{R} \approx 4.164$. This is a clear indication that if two co-channel cells are at a distance 4.164 x cell side away, channel interference can be negligible and good quality transmission is ensured. After considering Rayleigh fading and shadowing, a signal to noise ratio of 18 dB is considered adequate for any working system. Simulations in [2.11] have confirmed that for optimal performance in a practical cellular system (ensuring good coverage over $9/10$ th of the overall cell area) $D/R$ value 4.6 is adequate.

![Fig. 2.1: Representation of geographical areas in to hexagonal cells](image)

2.3 **Relation of re-use distance and cluster size**

Distance between two centres of hexagon is $\sqrt{3}$ times the cell radius ($R$).

$$D = \sqrt{(i^2 + j^2 + ij)} \quad 2.6$$

$i$ and $j$ are considered as shift parameters. The line connecting the centre of central cell and centers’ of the surrounding cell is separated by an angle of 60 degrees. Hence a cluster itself can be visualized as a large hexagon which includes same geographical area as any cluster. As shown on the figure below, number of cells contained in the large hexagon can be defined as:

$$N = i^2 + j^2 + ij \quad 2.7$$

By 2.6 and 2.7 it can be shown that
We can now determine minimum number of the cells in a cluster which will give optimum cell size.

\[ \frac{D}{R} = \sqrt{3} \times N \]  

Fig. 2.2: Relation of co-channel re-use distance and number of cells

For a cluster of size 7, reuse distance and cell side ratio \((D/R)\) is calculated to be \(\approx 4.6\) times and that is adequate to meet the cellular performance parameters as it provides \(C/I\) value of 17 \(dB\). In non ideal conditions with omni-directional antennas this value may go down to lower values. As discussed in [2.9], value of directional antennas improves \(C/I\) value.

2.4 Channel Reuse

Channel planning is an important function and should be taken up in the most meticulous after cluster size has been worked out. By using different values of shift parameters different clusters can be created. Once the cluster size is fixed, all available channels could be divided in co-channel sets and allotted to each cell of the cluster. The allocation of co-channels is repeated after re-use distance. Fig. 2.4 shows a compact pattern formed by considering \(i = 2\) and \(j = 1\). Different colours depict the cells which use co-channel sets. Same colour cells can be allotted same set of channels without degradation in performance due to co-channel interference. Any cell could be taken as a reference. Then traverse \(i\) cells along a side and take 60 degrees turn clockwise to move \(j\) number of cells.
2.5 **Channel Planning**  
Channel planning demands careful consideration of adjacent channel interference. This depends on the hardware capability to filter out unwanted interference due to adjacent channels. Even though spacing of 30 KHz may be provided, it is always preferred to assign adjacent channels as far apart as possible. For a 7 cell cluster, the distribution of 21 channels is depicted in fig 2.4. As evident, it is not possible to completely avoid the effects of adjacent channel interference as central cell channels will have to be adjacent to some channels in neighbouring cells.
Fig. 2.4: Distribution of 21 channels after considering adjacent channel interference

2.6 **Cell Structure.** Wireless coverage area will be divided into adjoining cells to ensure every cell is covered adequately by a Base Station (BS). Calls within a cell are handled by one BS and as the Mobile Subscriber (MS) move in to another cell, call is to be handed over to new cell. Special provisions have to be made to ensure handovers do not fail.

2.6.1 Service area can be divided into Macro cell and Microcell. Macro cells have radii of several Kms containing many microcells. BS in a microcell transmits low output power. MS also transmits low power. Microcells are more sensitive to traffic and interference variations than macro cells. Seven cell cluster is shown below.

2.6.2 *Microcell/ Macrocell Overlay system.* Microcells are surrounded by the macrocell. Overlay cell system is useful for the fast moving MS as number of the handoffs are much less since such MS are attached to the overlay cell. Microcells are useful for the location registration.
2.6.3 **Rectangular cell Plan.** This plan considers cells to be rectangular and BS to be placed between two rectangles. BS covers half of both the rectangles. This plan ensures the corners and screened areas get illuminated.

![Rectangular cell plan](image)

**Fig. 2.7: Rectangular Cell Area**

2.7 **Multiple Channel Bandwidth System.** This system can be used within a cell to improve spectral efficiency. In a multiple channel bandwidth system (MCBS), a cell is divided into two or three ring shaped regions with different bandwidth channels. So a 30 KHz channel, used in outermost ring can be reduced to 15 KHz in the middle ring and 7.5 KHz in the innermost ring. This concept is based on the fact that higher bandwidth channel requires lower C/I than a narrow bandwidth channel.

![Multiple channel service area](image)

**Fig. 2.8: Multiple Channel Service Area**

2.8 **Cell Radius and cell site positioning** It may be ideal to place contiguous homogenous cells across the entire geographical area, however it may not be practically feasible. As demands grow, radius of a cell may be reduced. By reducing cell radius to half, it may permit
reuse of frequency more often. There may be times when two size cells will co-exist. This will demand careful study and consideration in order to ensure minimum reuse distance requirements. The use of channels in the smaller cell will not cause problem in the larger cell system because transmitter power has been adjusted as per the lower cell requirements. Co-channels of the larger cells will have interference problem in case re-use distance is not respected. In such cases channels are normally divided between larger cell group and smaller cell group. Channels of the large cell group are used in the large cell area. Whereas channels in the smaller cell area are the co-channel sets of the larger co-channel cells.

AMPS systems are permitted to arrange their cells leaving a gap of the one quarter of the cell radius. As we discussed earlier in this chapter, that transmission quality of approx 90% of the coverage area should have a minimum of 18 dB. At the same time mobile cannot exceed transmission power beyond certain laid down limits (maximum of 20 watts in such cases). Minimum cell radius does not have very significant effect on the cost of system or the call quality; however it increases the handoffs.

Cellular network receives demands from the subscribers (referred as offered traffic) and it may process a fraction of those demands successfully depending on the reuse constraints (referred as processed traffic) Offered traffic varies depending on the location, time of the day, month of the year, special occasion etc. hence varying traffic intensity measured in Erlangs and circuit centum seconds (CCS). One Erlang refers to one circuit in continuous use. Call holding times may vary and typical values may range from 2 to 3 minutes.

\[ T(\text{inErlangs}) = \frac{(\text{number of calls in an hour}) \times (\text{average call holding time})}{3600} \]

Traffic intensity is also defined in CCS. One CCS in equivalent to one circuit being used continuously for 100 seconds.

\[ T(\text{inCCS}) = \frac{(\text{number of calls in 100 secs}) \times (\text{average call holding time})}{100} \]

In case all channels are preoccupied, offered traffic will be blocked. Hence blocking probability is also considered as grade of service (GOS). Lesser the value of GOS, better cellular network it would be.

2.9 **Channel Population for the cellular Network** Erlang proposed formula for the
GOS in cellular networks. In case of offered traffic $T$ and total number of circuits $N$, Erlang proposed the grade of service as

$$P_b = \frac{\frac{T^N}{N!}}{1 + \frac{T}{1!} + \frac{T^2}{2!} + \cdots + \frac{T^N}{N!}}$$  \hspace{1cm} (2.9)$$

Basic assumption here is that all blocked calls are cleared. This formula is referred as Erlang B formula. In case a blocked call is not cleared but queued in the system till it serviced then Erlang C formula is applied. In our thesis work we consider cases where blocked calls are cleared and are not queued.

2.10 Blocking Probability

We may consider that $M$ users demand service at an average rate of $v$, mutually independent to each other. Considering arrivals to be Poisson distributed, probability of receiving $n$ calls in time $T$ is

$$P = \frac{(vt)^n}{n!} e^{-vt} , \ n \geq 0;$$

If GSM network has $N$ channels, we can easily say the call duration or the time till when the call is being serviced is $S=1/ \mu$. The calls that are completed in time $T$ are distributed as Poisson random variable. Probability that $n$ calls are completed in time interval $T$ is:

$$P = \frac{(\mu t)^n}{n!} e^{-\mu t} , \ n \geq 0;$$

Blocking probability in cellular system, which allocates channels dynamically, can be computed using analytical methods. System can be modeled as Markov chain (2-D) to compute blocking probability. [2.9] shows that for 2-D cellular systems, “Distributed Dynamic Channel Allocation” schemes out perform as compared with the “Centralized Dynamic Channel Allocation” schemes in terms of blocking probability. 2-D cellular system is applicable to global systems for mobile communications (GSM). If we consider an infinite number of users $m \rightarrow \infty$ and call arrivals being independent to each other, then blocking probability of the system is given by Erlangs
Here \( k \) represents number of calls in GSM network at any time \( t \). \( \sum_{k=0}^{N} P_k = 1 \) and \( A = \frac{\mu}{v} \) represents offered traffic load.

### 2.11 Channel Efficiency

Channel efficiency (CE) is also an important factor. It is a ratio offered traffic in Erlangs and number of channels \( N \)

\[
CE(\%) = \frac{T}{N} \times 100
\]

Hence given a GOS, channel efficiency will increase with the increase in number of channels in cellular system. As a corollary, it is evident that more number of channels are allotted to cope with cell splitting.

### 2.12 Subscriber Density

Subscriber density (SD) refers to the number of subscribers in the system in a particular duration. Maximum number of calls that a cell can process depend on the number of channels available to that cell. In case of cluster of seven cells, number of calls in any given hour are as 1300, 1400, 1350, 1200, 840, 750 and 600. If we assume that 50% of the subscribers using their mobiles at the considered time and one call per mobile then subscriber density in the given area is as under:

\[
SD = \frac{\sum \text{number of calls in the cluster}}{0.5}
\]

\[
= \frac{7390}{0.5} = 14780
\]

### 2.13 Base Station Sleeping

In busy congested areas, cells are usually very small and large number of mobile are present in small areas. Base stations also tend to transmit large power in order to penetrate walled and interior areas. This phenomenon actually ends up in large overlap of coverage areas of different base stations. Traffic intensities also do not remain constant. They vary according to time of the day. Hence networks have to optimally adapt to the service requirement. In such cases power transmitted by base stations should be regulated based on traffic requirement. In [2.10] it is shown that network elements could be switched off in low traffic intensity cases. Call blocking probability is a deciding factor, which is calculated based on traffic arrival rate to mobile system. When ever, call
arrivals are slow, certain predefined base stations could be switched off, maintaining defined blocking probability. In the proposal given in [2.10], network is divided into disjointed areas called responsible region. Blocking probability of every responsible region is kept below the target blocking probability of system. It was shown that traffic aware base station sleeping algorithm saves considerable power. Fig 2.9 illustrates the overlapping coverage areas. It is evident that base station sleeping can be made effective without any considerable degradation in system performance.

Fig. 2.9: BS Responsibility Area [2.10]

2.14 Mobile Node Switching In this scheme, BSs are ranked based on the traffic load and are examined based on maximum load value. Mode switching from sleeping to active and the reverse are decided as under:-

2.14.1 To-activate: Power of the sleeping BS that meet the minimum mode holding time requirement is calculated based on traffic load of its neighbours. If it exceeds pre-decided threshold, it is switched on.

2.14.2 To-sleep: Power of the active BSs calculated by including the traffic of itself. If it is less than the given value, switching on will be considered.
Various channel Allocation schemes

2.15.1 Channel Borrowing Algorithms: Simple Borrowing (SB)  
In simple Borrowing strategy a channel set is assigned to each cell. When a new call arrives in a cell available channel may be allotted. If all channels of the cell are busy, an idle channel from neighboring cell can be borrowed provided it does not interfere with other channels already in use. In case no such channel can be found, incoming cell blocked. Usually such borrowings are carried out from a cell where most number of channels is idle.

2.15.2 Borrowing with Channel ordering (BCO)  
This scheme was proposed in [2.11] which proposes to use channel ordering. A set of channel are allotted to cell as done in FCA. These channels are arranged in ordered list. On arrival of a call, cell will search for channels that are wares in the ordered list and assign it. In case of non-availability: cell attempts to borrow a channel from cell where maximum numbers of such channels are available i.e. a channel is free and adheres to re-use contra ants. In case no such channel is found the call is blocked and released. As soon as call ends on a borrowed channel it is released. BCO engages that a channel cannot be borrowed under it is free in two or more co-channel cells.

2.15.3 Borrowing with Directional Locking (BDCL)  
This scheme was introduced by Zhang & Yuan in [2.12] to address efficiency issues of BCO. They proposed a directional locking of a borrowed channel. They proposed to loch a channel in one direction (towards the cell that has borrowed a particular channel) and not in the entire cell. As shown in the figure; cell may be sectored in two parts. Consider cell $C_1$ from where channel C has been borrowed by cell $C_2$. Hence $C_4$, $C_5$ & $C_6$ cannot borrow the channel due to reuse constraint. However cells on the opposite side of the cell $C_1$ i.e. $C_3$, $C_2$ & $C_7$ can demand and use the same channel C. This method improves efficiency. BDCL also use channel ordering when the call terminates.
2.15.4 Prioritized Channel Borrowing Algorithms. It is a flexible approach from a FCA where channels are allocated to a cluster. Each channel is given an identification number. Borrowing from heavily loaded cells is preferred. This scheme aims at smart borrowing of channel and its quick return as soon as the call terminates. Borrowing decision is made on the number of channels in use and its two co-channel cells. Hence, in a manner, first cell from where channel is to be borrowed is prioritized. Once a cell is selected, then selection of prioritized channel takes place.

2.15.5 Simple Timid Algorithm. It was shown in [2.13] that even simple timid algorithm does well as compared with centrally administered fixed channel allocation. Aggressiveness could substantially reduce blocking. Allocation algorithms could be divided into two classes. Timid algorithms achieve a saturation capacity of ≈ 43% and more aggressive algorithms can achieve saturation capacity up to 50%. Aggressive algorithms do more frequent configurations.
2.16 **Maximum packing Algorithm (MPA)** In [2.14] Kumar N Sivaraj introduced MPA as a greedy channel assignment algorithm. This assignment accepts a call whenever possible, even if, this involves rearrangement of the ongoing calls. Special care is taken that call in progress is not dropped to accommodate a new call. MPA was first introduced by Everitt *et al.* in [2.15]. Other dynamic channel assignment algorithms also permit reassignments however MPA has better performance.

2.17 **Contribution** Co-channel and adjacent channel interference limits the efficiency of any GSM network in terms of channel reuse. We propose a Persistent Aggressive Hybrid Channel allocation (PADCA) scheme in which only co channel reuse constraint have been considered. Proposed allocation scheme aims at reducing the blocking probability thereby ensuring better reuse of available channels. There is always a tradeoff between the availability of channels and blocking probability. As the No of available channels increase, blocking probability is to decrease keeping all other parameters same. Hence,every allocation algorithm aims at maximizing the reuse of channels keeping blocking probability in check. Different allocation schemes have been analyzed with different allocation constraints.

2.18 **Results and Discussion** It is conclusively assessed that a generic algorithm is useful and will outperform any timid and constrained allocation proposal. It is evident that Maximum Packing Algorithm proposed in [2.14] by Kumar N Sivarajan is a superior performance channel assignment algorithm. This could be taken as reference for comparison of the proposed allocation scheme. Hence finally proposed aim to design a DCA algorithm with the following characteristics:

- **2.18.1** To be general enough to obtain the algorithms described previously, as special cases;
- **2.18.2** To achieve even higher capacity gain than the algorithms described previously, at least for certain loads and services;
- **2.18.3** To be adaptive to changes in, for example, load, interference, shadowing, service type of the users, etc.;
- **2.18.4** To have relatively low implementation complexity and signalization overhead.
References


