CHAPTER 5

CAPACITY
ESTIMATION
5.1 INTRODUCTION.

The migration of CMCS from conventional frequency band of 800 - 900 or 1700 - 1800 MHz to 35-70 GHz range will make it possible to allocate large bandwidth of the order of 500 to 2000 MHz. The shift of frequency allocation is advocated to improve the capacity of the system. In case of existing CMCS (e.g. GSM) capacity of the system constitutes the major constraint. The capacity is directly influenced by the allocated bandwidth and interference from the adjacent cells. The use of 35-70 GHz frequency will not only allow higher allocation of bandwidth but interference will also be reduced due to the inherent higher attenuation at these frequencies.

5.2 C/I RATIO

In CMCS, although the frequency reuse scheme contributes to an increase in the system capacity, it also creates co-channel interference from co-channel cells as shown in figure 5.1.

Figure 5.1: Cellular layout for C/I estimation.
It is assumed that all the cells are of the same dimensions. Hence the co-channel interference becomes independent of transmitter power. Let the distance between two adjacent co-channel cells be \( D \) and the cell radius \( R \). The required \( D/R \) for avoiding co-channel interference is called co-channel reduction factor \( q \). Distance \( D \) is a function of \( K_t \) and \( C/I \),

That is \( q = \frac{D}{R} \) and \( D = f \left( K_t, \frac{C}{I} \right) \) \hspace{1cm} (5.1)

Where \( K_t \) is the number of co-channel interfering cells in the first tier and \( C/I \) is the received carrier-to-interference ratio at the desired BS. In a hexagonal-shaped cellular system, there are six co-channel cells in the first tier that contribute almost all the interference received by the desired MS in the center cell, as shown in figure 5.1.

That is \( \frac{C}{I} = \frac{C}{\sum_{k=1}^{K_t} I_k + n_o} \) \hspace{1cm} (5.2)

Where,

\( C \) -- Carrier power received by the desired MS
\( I \) -- Total interference
\( I_k \) -- Interference received from the co-channel cells
\( n_o \) -- Local noise.

From the results of the regression analysis of the 8-ray model (Table 4.11), it observed that the propagation characteristics in the frequency range 35-70 GHz show different path loss slopes within and outsides the cell. For further analysis it is assumed that the path loss slope in the active cell (desired MS) is \( n_1 \) and \( n_2 \) for the interfering signals.

That is,

\( C = R^{-n_1} \) \hspace{1cm} (5.3)

and \( I_k = D_k^{-n_2} \) \hspace{1cm} (5.4)
Where,

$D_k$ -- Distance from the transmitter of a $k^{th}$ co-channel cell to MS.

Hence $C/I$ becomes,

$$\frac{C}{I} = \frac{R^{-n}}{\sum_{k=1}^{6} D_k^{-n}}$$  \hspace{1cm} (5.5)

Assuming that all $D_k$ will not be much different from $D$, that is $D_k = D$.

Hence,

$$\frac{C}{I} = \frac{R^{-n}}{6D^{-n}}$$  \hspace{1cm} (5.6)

### 5.3 RADIO CAPACITY.

In conventional CMCS, the required $C/I$ is in the range of 14 - 18 dB.[279] Let $D_s$ be the required distance between the co-channel cells, then, using equation (5.6) frequency reuse factor $q_s$ is given as

$$q_s = \frac{D_s}{R}$$  \hspace{1cm} (5.7)

and assuming that all $C/I$ values have to be greater than the required carrier to interference ratio ($C/I)_k$, then

$$\frac{1}{6} \left( \frac{R^{-n}}{D_s^{-n}} \right) \geq \left( \frac{C}{I} \right)_k$$  \hspace{1cm} (5.8)

Let $K$ be the number of cells in a frequency reuse pattern. Then the relationship between $K$ and $q_s$ is found from the hexagon-cell configuration as

$$q_s = \sqrt{3K}$$  \hspace{1cm} (5.9)

Therefore,

$$K = \frac{q_s^2}{3}$$  \hspace{1cm} (5.10)

Using equation (5.7) the $K$ can be calculated as

$$K = \frac{1}{3} \left( \frac{D_s}{R} \right)^2$$  \hspace{1cm} (5.11)
Using equation (5.6) one can estimate $D_s$ in terms of $(C/I)_a$ as

$$D_s = \sqrt[3]{6R^n (C/I)_a}$$  \hspace{1cm} (5.12)

Hence using equation (5.11) and (5.12) $K$ is expressed as

$$K = \frac{1}{3} \left( \frac{\sqrt[3]{6R^n (C/I)_a}}{R} \right)^2$$  \hspace{1cm} (5.13)

The radio capacity is defined by \[112\]

$$m = \frac{B_t}{B_c \cdot K} \text{ number of channels / cell.}$$  \hspace{1cm} (5.14)

Where $B_t$ is the total allocated spectrum for the CMCS and $B_c$ is the channel bandwidth.

### 5.4 ESTIMATION OF CAPACITY FOR 35-70 GHz BAND.

#### 5.4.1 System Specifications.

The most popular system is the GSM, that uses the TDMA multiple access scheme. There are other standard systems such as ADC system specified by TIA in North America, JDC in Japan, that also use TDMA. For capacity estimation, GSM specification are taken as the reference.

The GSM system specifies many interfaces but only a part of the air-interface will be considered here. The frame and the slot structure are shown in figure 5.2. There is also a super and hyperframe (not shown in figure) for various purposes, e.g., synchronization and provision for MS to identify surrounding base stations.

There are eight voice channels on one carrier (full rate) with capability to introduce half rate speech codecs in the future. The carrier spacing is 200 KHz. Thus 25 KHz (200/8) is allocated to a full rate user. In all, there is a bandwidth of 25 MHz giving 125 radio channels i.e. 1000 traffic channels.
Figure 5.2: GSM slot and frame structure showing 130.25 bit per time slot (0.577 ms), eight time slots/TDMA frame (full rate) and 13 TDMA frames/multiframe.

The gross bit rate is 270.8 Kbps. The modulation scheme is GMSK with the normalized pre-Gaussian filter bandwidth equal to 0.30. The 33.85 Kbps per user allocation is as shown in Table 5.1.

<table>
<thead>
<tr>
<th>Data rate allocation per user</th>
</tr>
</thead>
<tbody>
<tr>
<td>speech codec</td>
</tr>
<tr>
<td>error protection of speech</td>
</tr>
<tr>
<td>SACCH (gross rate)</td>
</tr>
<tr>
<td>guard time, ramp up, synch.</td>
</tr>
</tbody>
</table>

The bits in the speech block (20 ms) consist of two main classes according to sensitivity to bit errors. The most sensitive bits (class 1) are protected by a cyclic redundant check (CRC) code and a rate = 1/2 convolutional code with constraint length equal to 5. The coded speech block is interleaved over eight TDMA frames to combat burst errors. To further enhance the performance, frequency hopping, where each slot is transmitted on different carriers, can be used by the system. This is a mandatory function for the MS but is optional for the system operator to use. There are two control channels associated with the traffic channels, the slow and the fast ACCH. The FACCH is a blank-and-burst channel and replaces a speech block whenever it is to be used. Two multiframe (see figure...
(5.2) are allocated for the slow associated control channel (SACCH). With full rate users the second SACCH frame is idle. In a SACCH frame the slots are assigned in the same way as for traffic frames. The gross bit rate on this channel is 950 b/s and the net rate is 383 b/s. A SACCH message is interleaved over four multiframes.

For locating the MS for hand-off purpose the GSM has chosen the method called Mobile Assisted Hand-off (MAHO). In this method the MS measures the signal strength on channels from neighboring BSs and reports the measurements to their current base station. The MTSO evaluates these measurements and determines to which BS the MS shall be transferred (hand-off) if the MS is about to leave its present cell.

Of the eight time slots in a TDMA frame, two are used on different frequencies for transmission and reception. In the remaining time the MS can measure the received signal strength on a broadcast control (BCCH) from its own and surrounding BSs. These measurements are averaged over a SACCH block (480 ms) before they are transmitted to the BS using the SACCH. The maximum number of surrounding BSs contained in the measurement list is 32 but only the results from the six strongest ones are reported. Thus the MS preprocesses the measurements and the report contains results from different BSs for every SACCH block. Since there is a possibility that the signal strength measurement can be affected by a strong co-channel and thereby be highly unreliable, the MS is required to identify the associated BS on a regular time basis. Therefore, it is necessary for the MS to synchronize to and demodulate data on the BCCH in order to extract the BS identity code. This code is included in the measurement report information transmitted to the MTSO.

The MS performs this identification process in its idle TDMA frame. There is one of these per multiframe. For half-rate, this idle frame is used for SACCH for the new traffic channel created. The MS measurement report also contains an estimate of the bit error rate on the traffic channel used. This additional information is useful to determine the radio link quality since the received signal strength measurement can not indicate a co-channel interferer or severe time dispersion.
5.4.2 Capacity Of The System At 35 GHz.

To estimate the capacity of a CMCS operating at 35 GHz following specifications are assumed.

<table>
<thead>
<tr>
<th>Table 5.1: CMCS specifications for capacity estimation operating at 35 GHz.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier frequency</td>
</tr>
<tr>
<td>Bandwidth allocated per operator</td>
</tr>
<tr>
<td>Carrier spacing</td>
</tr>
<tr>
<td>Gross bit rate</td>
</tr>
<tr>
<td>Speech codec bit rate</td>
</tr>
<tr>
<td>C/I required</td>
</tr>
<tr>
<td>Radius of the cell</td>
</tr>
</tbody>
</table>

From equation (5.12) and taking the values of \( n_1 \) and \( n_2 \) from the Table: 4.11, one can estimate the required \( D_s \) as

\[
D_s = 3.57 \sqrt[6]{6 \times 250^{1.5846} \times 63.09} = 60.6983 \text{ m.}
\]

The co-channel reduction factor \( q_s \) is equal to

\[
q_s = \frac{D_s}{R} = \frac{60.698}{250} = 0.24279
\]

The value of \( q_s \) can not be less than 1. Hence, let \( q_s \) be equal to ‘1’.

Therefore, the value of \( K \) will be

\[
K = \frac{q_s^2}{3} = \frac{1}{3} = 0.333
\]

From definition of \( K \), \( K \) can not be less than 1, hence for further calculations \( K \) is assumed to be 1.
From equation (5.14), one can estimate number of voice channels per cell as follows.

\[ m = \frac{B_t}{B_c \times K} \]

If we assume the value of \( B_t = 1 \) MHz, then

\[ m = 5 \]

The multiple access scheme assumed is TDMA in which the number of voice channels are 8 per carrier. Therefore number of voice channels per cell will be

No. of voice channels/cell = 5x8 = 40.

Similarly one can find the number of channels per cell for different values of \( B_t \). Table 5.2 lists the number of voice channels for various values of \( B_t \).

<table>
<thead>
<tr>
<th>( B_t ) (MHz)</th>
<th>No. of Voice Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>120</td>
</tr>
<tr>
<td>4</td>
<td>160</td>
</tr>
<tr>
<td>5</td>
<td>200</td>
</tr>
</tbody>
</table>

**5.4.3 Capacity of the System at 50 and 60 GHz.**

To estimate the capacity of a CMCS operating at 50 and 60 GHz, the specifications are assumed as mentioned in section 5.3.2 except carrier
frequency as 50 and 60 GHz. Using equation (5.12) and taking the values of $n_1$ and $n_2$ from the Table: 4.11, the values of the required $D$, and the co-channel reduction factor $q$, are calculated from these values of $D$, and $q$, $K$ is estimated. The values for $D$, $q$, and $K$ are tabulated in Table 5.3.

<table>
<thead>
<tr>
<th></th>
<th>35 GHz</th>
<th>50 GHz</th>
<th>60 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_1$ (m)</td>
<td>60.6983</td>
<td>86.666</td>
<td>47.404</td>
</tr>
<tr>
<td>$q$</td>
<td>0.2428</td>
<td>0.4952</td>
<td>0.4740</td>
</tr>
<tr>
<td>$K$</td>
<td>0.3333</td>
<td>0.3333</td>
<td>0.3333</td>
</tr>
</tbody>
</table>

As mentioned in section 5.4.2 the number of voice channels available per cell are estimated. For 50 and 60 GHz the value of $K$ will assumed to be 1. Hence the capacity of the CMCS operating at these two frequencies is as mentioned in Table 5.2.

### 5.5 CONCLUDING REMARKS.

In this chapter the capacity of the CMCS working in the 35-70 GHz band is estimated. The analytical model suggested by W. C. Y. Lee is used. The modification on the basis of propagation characteristics for estimation of the desired value for the reuse distance is performed. (equation 5.12)

The CMCS specification for the capacity estimation are opted on from GSM specifications. For these specifications, desired reuse distance and the reuse factor are estimated. The value for the reuse factor at 35, 50 and 60 GHz are 0.24279, 0.4952 and 0.4747 respectively. From the this value of reuse factor the value $K$ is estimated. The results show that the value of $K$ is 0.333. From the definition of $K$ it is clear that the reuse distance can not be less than 1. Hence the value of $K$ is assumed to be ‘1’. The capacity of the CMCS operating in the band of interest is as mentioned in table 5.2.