CHAPTER 3. MOBILE RADIO INTERFERENCE

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The usefulness of a communication system is limited by its overall noise contents. The above statement can be interpreted as meaning that a signal is detectable only when its level at the receiver output is greater than the noise. Therefore, the minimum detectable signal level of the system corresponds to a receiver output SNR of unity.

The required ratio of the wanted signal level to unwanted signal level is always a key factor when designing a radio communication system. The various sources of interference that influence the system can be categorised into two general classes:

* Intra system interference - due to system under consideration [26],[51].
* Inter system interference - due to other radio systems and natural or man made noise [13],[27].

We are limiting our discussions to Intra system interference factors which must be considered when designing a mobile communication system.

A primary design objective for mobile radio system is to conserve the available frequency spectrum by reusing allocated frequency channels in areas that are geographically located as close to each other as possible. The limitation in distance for reusing
frequency channels can be determined by the amount of co-channel interference [7]. The separation between adjacent channels and the assignment of frequency channels within specified geographic areas is limited by the system parameters for avoidance of adjacent channel interference. To achieve a satisfactory frequency channel assignment plan it is necessary to fully understand the effects of co-channel and adjacent channel interference on mobile radio reception.

The other type of interference which is inherent in the nature of mobile communication system is Near-to-Far End Ratio Interference. This occurs because at times the mobile unit may be too close to an undesired transmitter and too far away from the desired transmitter.

For this purpose at a particular site and at a particular time under consideration the desired signal must be separated from the interference in power level and or in frequency so that protection from undesired signal is built into the system.

It is then convenient to determine the RF signal level to find the level separation between co-channel and adjacent channels, which is sufficient to determine the signal strength of desired and undesired signals in order to assess the existence and magnitude of resulting output interference.
3.1 CO-CHANNEL INTERFERENCE

The co-channel arrangement is when two or more communication channels are assigned to the same frequency. The purpose of doing this is to increase the spectrum utilization. In co-channel environment, two or more co-channel communications are on the air and even though there is a large deviation in FM or PM, it does not help to reduce the interference.

If a channel reuse plan is not well designed it will cause co-channel interference in the system, affecting the performance of whole system. The minimum distance at which the co-channel interference can be ignored is determined by first specifying the required carrier to interference ratio (C/I) at the signal reception, then relating the C/I to the propagation path loss, which is in terms of propagation distance [45].

The minimum reuse distance may then be calculated with reference to the received carrier to interference ratio.

\[
\text{C/I (dB)} = 10 \log \left( \frac{R}{D} \right)^n + 10 \tag{3.1}
\]

Where 
- \( R \) : Wanted signal range.
- \( D \) : Unwanted signal range.
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\[ n \] Propagation decay law appropriate to the environment being studied, where \( 2 < n < 4 \) typically.

In the case of multiple interfering sources a cellular type approach is taken, postulating six equally spaced interferers giving:

\[ \frac{\text{C/I (dB)}}{10\log \left( \frac{1}{6} + \left( \frac{R}{D} \right)^n \right)} \]  \hspace{1cm} (3.2)

A parameter, so called co-channel reduction factor, is used to describe the carrier to interference ratio of two co-channels in different areas.

Each antenna have signal coverage in its own cell of radius \( R \). If the distance between two co-channel cells is \( D \). Then the ratio of \( D/R \) is used as a key parameter in dealing with co-channel interference.

\[ p = \frac{D}{R} \]  \hspace{1cm} (3.3)

The value \( p \) is called co-channel reduction factor and can be determined for any level of signal to interference ratio. Therefore, a good multi antenna site configuration with a large area should be based on the co-channel reduction factor.
3.1.1 AVERAGE CASE

To determine the value p for a co-channel interference environment in which carrier to interference ratio is greater than 48dB or equal to 63.1. We have:

\[ \frac{C}{(N + I)} = \frac{C}{(N + \sum_{j=1}^{M} I_i)} \]  
(3.4)

Where M is the number of interferers. In a fully equipped cellular system there are always six co-channel interfering cells.

Co-channel interference can be experienced both at the cell site and at a mobile unit in the cell.

For \( M = 6 \) and a path loss of 40dB/dec. (i.e. loss is \(-4\) proportional to \( R \)) used in a mobile radio environment, the carrier to interference ratio received at a desired cell site (base station) and at the desired mobile unit is shown in Fig-3.1 and Fig-3.2 respectively. \( C_b \) and \( C_m \) are carrier levels. \( N_b \) and \( N_m \) are are local noise levels, \( I_i \) and \( I_i' \) are interference levels. The letter \( b \) stands for the base station and the letter \( m \) stands for the mobile unit.

If the interference is much greater, then the carrier to noise interference ratio \( C/I \) at the mobile unit caused by
Fig. 3.1: CO-CHANNEL INTERFERENCE AT DESIRED CELL SITE
Fig. 3.2: CO-CHANNEL INTERFERENCE AT DESIRED MOBILE
the six interfering sites is the same as the C/I received at the centre cell site caused by interfering mobile units in six cells.

According to both the reciprocity theorem and the statistical summation of radio propagation, the two C/I values are very close.

C/I is normally specified to be 18dB or higher based on subjective tests and voice quality criterion.

Carrier level \( C_b \) and \( C_m \) should be equal because reciprocity holds. Noise levels \( N_b \) and \( N_m \) will be different by 1 or 2dB. The local noise is usually much less than the interference and can be neglected.

Since there is only a slight difference between these two cases, the above equation can be generalised for the cases when interferers are equidistant from the desired cells.

The equation (3.4) becomes:

\[
\frac{C}{I} = \frac{C}{\sum_{i=1}^{6} I_i} = R/60
\]

\[
= \frac{4}{\rho/6} \geq 63.1
\]

(3.5)
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It has also been assumed that interference level is much stronger than the local noise level. As such the local noise is negligible as compared to the interference level. From the above equation we get:

\[ p = 4.41 \]  \hspace{1cm} (3.6)

DISCUSSION

The results have been obtained for a C/I of 18 dB and a path loss slope of 4. The results imply that:

1. The factor \( p \) is independent of transmitted power as long as the transmitted power is above a minimum value. The determination of minimum transmitted power is based on the signal to noise ratio in a noise limited environment.

2. Factor \( p \) is dependent upon the number of interferers, as long as the transmitted power at every co-channel cell site is the same. Any transmitted power value can be used without changing the carrier to co-channel interference ratio.

3. The C/I of 18 dB is measured by acceptance of voice quality from mobile receiver. The acceptance implies
that both mobile radio multipath fading and co-channel interference become ineffective at that value.

4. Co-channel interference can be reduced by other means also, such as using directional antenna, tilting antenna beams, lowering antenna height, choosing the proper site, etc.

5. Usually, a value of $p$ greater than that described by equation (3.6) would be desirable. The greater the value of $p$, the lower the co-channel interference. In the real environment the value of $p$ as determined above may not be large enough to maintain a carrier to noise interference ratio of 18 dB. This is particularly true in the worst case.

3.1.2 WORST CASE

It has been shown that, the same channel can be reused at a certain distance governed by the co-channel reduction factor. The value of $p$ will increase if the number of co-channel sites increase. Even for the same number of co-channel sites the cases considered are described in Fig-3.3. The distance from all six co-channel interfering
Fig. 3.3: CO-CHANNEL INTERFERENCE WORST CASE
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sites are also shown in the figure. There are two
distances of D-R, two distances of D and two distances of
D+R.

The worst case is at the location where the mobile unit
would receive the weakest signal from its own cell site
but strong interference from all the interfering cell
sites. In the worst case the mobile unit is at the cell
boundary as shown in figure.

Let \( p_1 \) be the co-channel reduction factor of an average
case, then:

\[
p_1 = \frac{D}{R}
\]  

(3.7)

For the average case it has been shown that value of \( p \) has
to be greater than 4.41 in order to have a C/I ratio of
18dB based on 6 equally distant co-channel interferers.

However, if the worst case is considered for co-channel
cells, the distance between the co-channel cell site and
the mobile unit is D-R.

The new parameter \( p_1' \) for the worst case is defined as:

\[
p_1' = \frac{(D - R)}{R} = p_1 - 1
\]  

(3.8)
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The carrier to interference ratio with six co-channel equally distant interferers can be expressed as:

\[
\frac{C}{I} = \frac{C}{\sum_{i=1}^{6} I_i} = \frac{R}{6 + (D - R)}
\]

\[
p_1'' = \frac{4}{63}
\]

(3.9)

Let \(\frac{C}{I}\) be 18dB or above i.e value of 63.1 then:

\[
p_1'' \geq 63
\]

(3.10)

In this equation if \(p_1'' = 4.41\) then the co-channel reduction factor becomes:

\[
p_1 = p_1'' + 1 = 5.41
\]

(3.11)

Thus, in a ideal flat terrain with a required \(\frac{C}{I} = 18dB\) the factor \(p\) obtained for a worst case is:

\[
p = \frac{D}{R} = 5.41
\]

(3.12)

Therefore, co-channel has to be assigned at distance \(D\) which is 5.41 times radius of the cell.

\[
D = 5.41R
\]

(3.13)
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DISCUSSION

In reality, because of the imperfect site locations and the rolling nature of the terrain configuration, the C/I received is always worse than 17 dB and could be 14 dB or lower. In that case, a co-channel interference reduction factor of $p = 4.41$ is insufficient. Thus the system should be designed for the worst case around the carrier to interference ratio C/I and a co-channel interference reduction factor of $p = 5.41$.

However, in the real environment

$$D = 6R$$  \hspace{1cm} (3.14)

is used for a system for omni-directional antenna cell.
3.2 ADJACENT - CHANNEL INTERFERENCE

The design of a mobile system must include measures to limit not only co-channel interference but also adjacent channel interference [41],[45].

Adjacent channel interference has slightly better control than co-channel interference. The filter characteristics can help to reduce the interference. There is in-band and out-band adjacent channel interference. The former is similar to co-channel interference and it can not be filtered. Out of band interference is the adjacent channel interference that is being considered.

Although the IF filter of receiver significantly attenuate signals from the channels adjacent in frequency to the desired channel, it is advisable to avoid circumstances in which the received levels of adjacent channel greatly exceed that of the desired channel. Thus situation would arise at a base station. for example, if one mobile were many times farther away from its serving base station than another mobile being served by the same base station on an adjacent channel. In the presence of fading, severe adjacent channel interference would result unless the receiver. IF filters could greatly attenuate the adjacent channel. In general, a substantial
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spectral guard band would be required between channels to permit IF filters to reject the interference adequately. The adjacent channel interference can be reduced by the frequency assignment.

The term Adjacent channel interference includes next-channel interference and neighbouring channel interference. These terms are defined below:

3.2.1 NEXT CHANNEL INTERFERENCE

This is caused by the channel next to the operating channel. Next-channel interference affecting a particular mobile unit can not be caused by transmitters in the common cell site, but must originate at several other cell sites. This is because any channel combiner at the cell site must combine the selected channels normally far away from the desired one. Therefore, next-channel interference will arrive at the mobile unit from other cell sites if the system is not designed properly. Assuming the channel filter characteristics as a 6 dB/oct slope in the voice band and a 24 dB/oct fall outside the voice band region. If the next-channel signal is stronger than 24 dB, it will interfere with the desired signal. The filter with a sharp fall off slope can help to reduce the adjacent channel interference.
3.2.2 Neighbouring Channel Interference

The channels which are several channels away from the next channel will cause interference with the desired signal.

This situation would arise at a site, for example, if one mobile were many times farther away from its serving base station than another mobile being served by the same base station on an adjacent channel. With a distance ratio of 10, for instance, the received level of the adjacent channel at the cell site could easily be 40dB higher than the level of the desired channel. In the presence of fading, severe adjacent channel interference would result unless the receiver IF filter could greatly attenuate the adjacent channel.

3.2.3 Analysis

Assume that the filter has a slope 6dB/dec and that the bandwidth of each channel is 30KHz. The frequency at the edge of the channel is 15KHz from the centre frequency. Starting from the edge of the channel, we may follow the 6dB/dec loss and carried over the frequency range. If the frequency is 240 KHz away from the centre of the desired channel, then the loss can be found by substituting \( f_1 = 15 \text{ KHz} \), \( f_2 = 240 \text{ KHz} \) and \( K = 6 \) in the equation given below:
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\[ \text{Loss} = K \log \left( \frac{f_2}{f_1} \right) \]

\[ = \frac{K \cdot \log (f_2/f_1)}{0.3} = 24 \text{ dB} \] (3.15)

This means that there will be a loss of 24 dB if the power is received at a frequency separated by 240 KHz. Of course the losses due to geographical separation and antenna direction will be added up, along with the loss due to frequency separation.

Additional path loss is given by:

\[ \text{Path loss} = 40 \log \left( \frac{d_1}{d_2} \right) \] (3.16)

Where \( d_1 \) and \( d_2 \) are the distances from two co-channel sources to the base station receiver in a cell and \( d_1 \) is greater than \( d_2 \).

Comparing equation (3.15) and (3.16) we get:

\[ \frac{4}{K/3} (d_1/d_2) = (f_1/f_2) \] (3.17)

\[ f_1 = f_2 (d_1/d_2) \] (3.18)

Fig. 3.4 describes the relationship between ratios of frequencies and distance.
Fig. 3.4: RELATIONSHIP BETWEEN FREQUENCIES AND DISTANCE
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The problem of adjacent channel interference can be significantly reduced by developing a frequency allocation plan that ensures an adequate frequency separation between adjacent channels. Also, the use of high-gain bandpass filters in the receivers will assist in reducing adjacent channel interference. One of the few advantages that results from time-delay spread within the mobile-radio environment is that the delay spread tends to decorrelate the adjacent channel frequency toward the desired channel, and thus reduces adjacent channel interference.

DISCUSSION

1. Adjacent channel noise will have a greater effect on the 12.5 KHz radios than on 25 KHz. As the noise transmitted by the transmitter increased logarithmically as transmitting carrier frequency is approached.

2. Fig. 3.5 represent the transmitter noise of a typical 25 KHz transmitter modulated with multiple tones. Simulating speech at a deviation of ± 2.5 KHz with the received frequency, 10 KHz removed from the transmitting frequency, the transmitter noise is only 30dB below the carrier level. At 20 KHz removed the
Fig. 3.5: TYPICAL TRANSMITTER NOISE
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noise is 70dB below the carrier and at 50 KHz and
greater, removed approx. 85dB below the carrier.

The effect of this is that where a transmitter is
operating in close proximity to a receiver on an
adjacent channel, the receiver effective sensitivity
will be reduced by the transmitters noise spectrum.
This reduction in receiver sensitivity will impact
the attainable communication range.

3. The adjacent channel interference can be reduced by
considering the losses from :
   * Geographical separation, D/R
   * Frequency separation, f2 - f1

4. Improving receiver design reduces the adjacent
channel interference, but co-channel interference can
only be managed by a good frequency management
scheme.

5. As a final consideration, when adjacent channel
interference is compared with co-channel interference
at the same level of interfering power, the effects
of adjacent channel interference are always less.
3.3 NEAR-TO-FAR END RATIO INTERFERENCE

Near-end to far-end ratio interference occurs when the distance between the mobile receiver and the base station transmitter becomes critical with respect to another mobile transmission that is close enough to override the desired base station signal [41]. This situation usually occurs when a mobile unit is relatively far from its desired base station transmitter at a distance of d1, but close enough to its undesired nearby base station transmitter at a distance d2 such that d1>d2. Under such conditions if the two transmitters are assumed to be transmitting simultaneously at the same power, then the signals received by the mobile unit from the desired source will be masked by the signals received from the undesired source.

This same type of interference can occur at the base station when signals are received simultaneously from two mobile units that are at unequal distances (one close, the other far) from the base station. In this case, the closer mobile transmission at distance d2 may interfere with the distant mobile transmission at distance d1. The power distance due the path loss between the receiving location and the two divergently located transmitters is
called the near-end to far-end ratio interference and can be expressed as:

\[ \text{Near-end} = \frac{\text{Path Loss d1}}{\text{Path Loss d2}} \]  
\[ \text{Far-end ratio} \]  

To obtain a quick approximation of the near-end to far-end ratio, a propagation loss slope of 40dB per decade can be used for a typical mobile-radio environment. Then the following expression is valid:

\[ \text{Near-end to Far-end ratio} = 40 \log \text{(distance ratio)} \]  
\[ \text{(3.20)} \]

**DISCUSSION**

Considering the case where a base station is simultaneously serving two mobile units. One mobile unit is 0.1 Km from the base station and the other is 15 Km distant. Under these conditions, the near-end to far-end ratio can be approximated by first determining the distance ratio:

\[ \text{Distance ratio} = \frac{15}{0.1} = 150 \]  
\[ \text{(3.21)} \]

The distance ratio then applied to the propagation loss slope for the mobile radio environment.
Near-end to far-end ratio

\[ \text{Near-end to far-end ratio} = 40 \log_{10} 150 = 87 \text{dB} \]  

If the required signal-to-interference ratio is 15 dB, then the adjacent channel frequency separation must be far enough apart to provide a minimum of 102 dB (87 dB + 15 dB) of signal isolation between the two adjacent channels.