

Co-channel and Adjacent Channel Interference Calculations in Cellular Communications Systems

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Abstract. Signal to Interference ratio (S/I) calculations for corner excited cellular communications systems based on median mobile-to-base and base-to-mobile signal powers for co-channel interference and immediately adjacent as well as non- immediately adjacent channel interference is presented. The mathematical model includes most related system parameters, such as, cluster size, filter characteristics, propagation exponent, tier coverage, and directional antennae front-to-back ratio. Both mobile-to-base and base-to-mobile cellular communications are investigated. The calculated results proved that the effect of adjacent channel interference compared to co-channel interference cannot be ignored in general and may have severe performance degradation under some specific operating environments, for a particular system architecture.

Introduction

The fundamental principle of cellular systems is that a limited radio bandwidth has the potential to support a large number of users by means of frequency reuse. Two limiting factors relating to this matter are co-channel interference and adjacent channel interference. The former is produced by simultaneous use of the same frequency channel in different spatial cells. The latter is caused due to spill over of emissions in immediately adjacent channels as well as non- immediately adjacent channels. Tighter filtering transition characteristics (emissions mask) and receiver filtering are important in high-performance cellular systems.

The signal -to- interference ratio considering co-channel and adjacent channel interference was investigated by many authors [1, p.351; 2-8]. Furthermore, a mathematical analysis for calculation of the ratio of median signal power to the sum of median interference powers was presented by Rappaport [9]. This analysis assumed that mobiles and base stations employ Omni-directional antennas.

In previous related work, emphasis was focused on centre – excited systems. In this investigation, emphasis is focused on corner - excited systems, i.e., system with three – corner base stations using directional antennas. The three 120° rather than six 60° sector directional antennas will be employed and studied to provide 360° of coverage. Each base station serves three neighboring cells and each cell is served by three different base stations located at its vertices as shown in Fig.1. The three sector is generally used with a seven-cell repeat pattern, giving an overall requirement for 21 channel sets [10, p.73]. The improved co-channel rejection in the six sector, however, particularly the rejection of secondary interferes, results in a four-cell repeat patterns being possible, but needs an overall requirement of 24 channel sets.

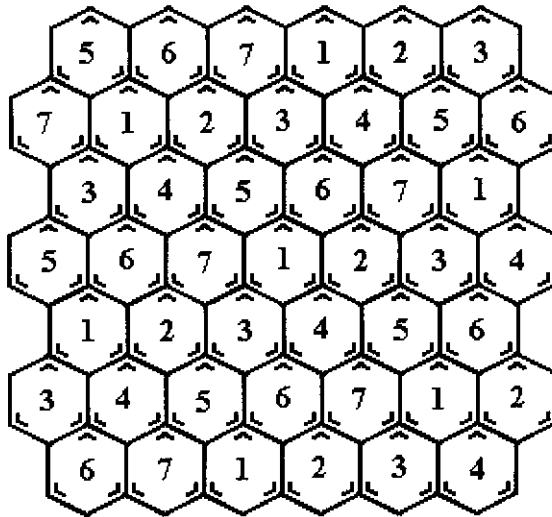


Fig.1. Cellular system architecture.

The major advantage of using directional antennas is that a large portion of the interference is attenuated by the antenna front-to-back ratio for both mobile-to-base and base-to-mobile communications. However, a disadvantage of sectorization is that larger number of channel sets required results in fewer channels per sector, and thus a reduction in trunking efficiency, which means that the total traffic that can be carried for a given grade of service is reduced. Never the less, the capability to use much smaller cells through sectorization outweighs such drawbacks, and the end result can be a higher capacity system.

Analytical Model

We assume flat smooth terrain tessellated by regular hexagonal cells, we also assume fixed channel assignment is used in the cellular communication system. The allocated spectrum is divided into equal communication channels. The channel sets are formed by dividing the total number of usable channels into N groups, (the cluster size), and is related to the displacement parameters (I, J) that identify co-channel cells by

$$N = I^2 + IJ + J^2 \quad (1)$$

where I and J are non-negative integers with $I \geq J$.

System parameters are defined as follows; transmitter filter characteristics β , and receiver filter characteristics α are flat over the desired channel bandwidth at frequency f_c and have an attenuation of α or β dB/Octave outside the desired channel bandwidth. That is, the relative attenuation between the edge of the channel $W/2$, and W is α dB, and between W and $2W$ is another α dB, etc.

The received median signal strength of the log-normal distribution is inversely proportional to the distance raised to the power γ , where exponent γ is typically 3.6 to 4 in urban areas, 3 to 5 in built-up area and 1 to 6 within buildings [11,12]. Finally, it is necessary to introduce an additional new parameter, μ , the antenna front-to-back ratio in dB, in addition to the above previous parameters used in Lee's model [13].

In this new model, it is assumed that the 120° directional antennas implemented by base stations have perfect directivity, i.e., ground clutter is not considered, and multi-path propagation is also ignored. Furthermore, analysis deals only with median signal-to-interference ratio.

Mobile-to-Base Signal-to-Interference Ratio

Land mobile radio propagation is characterized by two main factors. First, by power-law propagation such that the median received power decreases with range raised to some exponent (γ). The received power at a fixed range is not constant; rather it tends to be log-normally distributed with a median value set by the power-law propagation. The standard deviation is controlled by the diversity of environments experienced, and values on the order 8 to 10dB are common over distances of miles. The second factor is log-normal-shadowing, where at distance scales less than 100 wavelength, the average power is essentially constant. None the less, substantial changes in the signal envelope may occur with movements of just one quarter wave length (λ), [14].

In this model, a performance measure discusses nominal and worst position arrangement respectively. In the nominal case, the locations of desired mobile, interfering mobiles, and receiving base station antenna are assumed as shown in Fig.2.

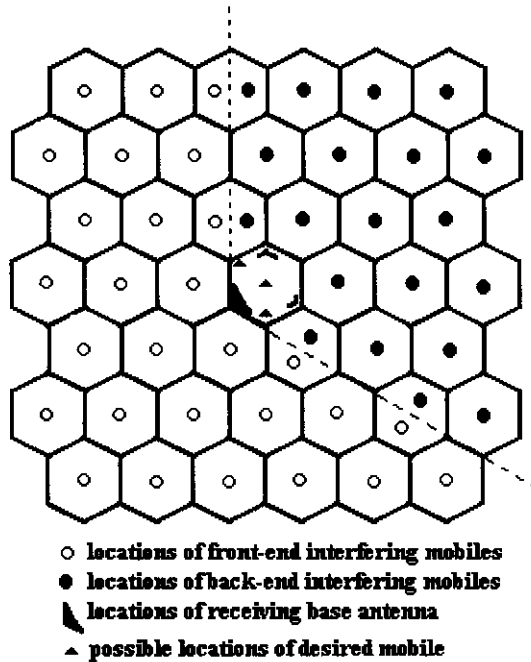


Fig.2. Mobile-to-base antennas arrangement.

Each cell is served by three directional antennas of three different base stations. It is obvious that co-channel interference seen by all three directional antennas, are the same due to symmetrical architecture considered, while signal-to-interference seen at the three directional antennas considering both co-channel and adjacent channel interference are different. The maximum distance between a mobile and its nearest neighboring base antenna is equal to the cell radius R , hence, it is reasonable to assume that the desired mobile is located one cell radius away from the receiving base antenna. Consequently, for this nominal mobile-to-base signal-to-interference corresponds to mobiles uniformly distributed over the cell, while the interfering mobiles are located at the cell centre.

Nominal median mobile-to-base signal-to-interference ratio

The relative attenuation between the edge of the channel $W/2$, and W is α dB, and between W and $2W$ is another α dB, etc. The frequency separation between the immediately adjacent channels is also taken as W . Suppose the interfering signal is m

channels, ($m = 1, 2, \dots$), away from the desired signal. The frequency separation between these two signals is mW . To identify the signal isolation due to frequency separation, it is considered those two mobiles equally distant from the receiving base station and emitting on different channels. If the median signal – to – interference ratio measured at the receiving base station is to be a given SIR dB, the interfering signal must have a frequency separation of

$$mW = 2 (\text{SIR dB} / \alpha \text{ dB / octave}) \cdot W / 2$$

Solving for SIR_{dB} , then $\text{SIR}_{\text{dB}} = \alpha (1 + \log_2 m)$. The resultant SIR in terms of α and m is

$$\text{Signal-to-Interference } S/I = 10^{(\alpha/10)} m^{(\alpha/10 \log 2)} \quad m > 0 \quad (2)$$

In the calculation of the median mobile – to – base signal – to – interference ratio, a worst case analysis assumes a desired signal from a mobile at a vertex of the reference cell. The interfering signals come from all the mobiles both inside and outside the reference cell. These signals are both co-channel and adjacent channel signals with respect to the desired signal.

The model employed is that used in [13]. The received filter characteristic is flat over a bandwidth W centered at a frequency f_c and has an attenuation of α dB / octave outside the bandwidth. The long term median value of signal power decreases with increasing radial distance from a mobile to base. The power decrease is inversely proportional to some exponent of the distance γ .

Suppose that at the receiving base station, the desired signal is from a mobile at a distance d_s , and the interfering signal is from another mobile at distance d_I . Then if the desired mobile signal and the interfering mobile signal have the same transmitter power and use the same channel, the median S/I ratio measured at the receiving base station will be;

$$S/I = (d_S / d_I)^{-\gamma} \quad (3)$$

For the purpose of further calculations, it is convenient first to find the reciprocal ratio, i.e., interference – to – signal ratio I/S. Define the distance from the centre of a cell to a vertex as the cell radius R . Suppose the desired signal comes from a mobile at a vertex of the referenced cell, exactly one cell radius R from the receiving base station.

The interfering signal comes from a mobile at distance d_I from the base station, and has frequency separation mW with respect to the desired signal. The median interference-to-signal ratio measured at the receiving base station is

$$I/S = (d_I / d_S)^{-\gamma} = (d_I / R)^{-\gamma} \quad (4)$$

Since the unit length is taken as the distance between centres of nearest neighboring cells,

$$R = 1/\sqrt{3} \quad \text{And hence } I/S = (3d_I^2)^{-(\gamma/2)}$$

It can be concluded that the median I/S ratio measured at the receiving base station when there is only one interfering signal can be calculated as follows;

(i) For co-channel interference ($m = 0$)

$$I/S(d_I, \gamma, m, \alpha) = (3d_I^2)^{-(\gamma/2)}$$

(ii) For m th adjacent channel Interference ($m > 0$)

$$I/S(d_I, \gamma, m, \alpha) = (3d_I^2)^{-(\gamma/2)} 10^{-(\alpha/10)} m^{-(\alpha/10 \log 2)}$$

The above discussion can be now generalized to include interference from one interfering cell and to include interference from all other cells within that cluster size (N) respectively.

To simplify calculations, it is assumed all the adjacent channel interference arises from mobiles at the average distance away from the receiving base station, i.e., $(2/3)R$. Then the nominal I/S ratio measured at the receiving base station when the interfering signals come from all adjacent channels within the reference cell can be calculated as follows;

$$I/S = \left(\frac{2}{3}\right)^{-\gamma} \cdot 10^{-(\alpha/10)} \left\{ \sum_{K=1}^{K_2} (KN)^{-(\alpha/10 \log 2)} + \sum_{l=1}^{l_2} (lN)^{-(\alpha/10 \log 2)} \right\} \quad (5)$$

Where K_1 and l_1 are positive integers such that there are (K_1+1) interfering channels are greater, and (l_1+1) lesser, than the frequency of the desired channel, or vice versa. Similarly, K_2 and l_2 are positive integers such that there are K_2 interfering channels which are greater, and l_2 lesser than the frequency of the desired channel.

Using the results obtained above, the nominal I/S ratio produced at the receiving base station of the reference cell by interfering signals from any interfering cell within the cluster can be calculated. By assuming these nominal I/S values for all cells within the cluster, the overall nominal I/S ratio is obtained. It should be noted that the desired signal comes from a mobile at a vertex of the reference cell and all interfering signals come from all the channels in all the cells within the cluster. Thus,

$$I/S_{\text{overall}} = I/S_{\text{reference cell}} + \sum_{\text{all adjacent channel}} I/S + \sum_{\text{all co channel}} I/S \quad (6)$$

Under uniform distribution assumption, the probability that an interfering mobile located at the front-end half-cell or the back-end half-cell is 0.5. Thus, for a given channel, normalized interference introduced by an interfering mobile located at the centre of the front-end half -cell may be calculated, by multiplying its probability 0.5. The same calculations including attenuation for an interfering mobile located at the centre of the back-end half-cell can be done. The sum is the normalized interference introduced by the given channel used by an interfering mobile at that cell.

Worst position mobile-to-base signal-to-interference ratio.

In the calculation of the nominal median mobile-to-base S/I , it was assumed that all interfering signals to originate from mobiles at the centre of the interfering cell, excluding the reference cell is $[3(t^2 + tj + j^2)]$. However, in the calculation of the worst case median mobile-to-base S/I , the model must be slightly modified to include all the interfering mobiles in the interfering cell, located as close to the receiving base station as possible as shown in Fig. 3.

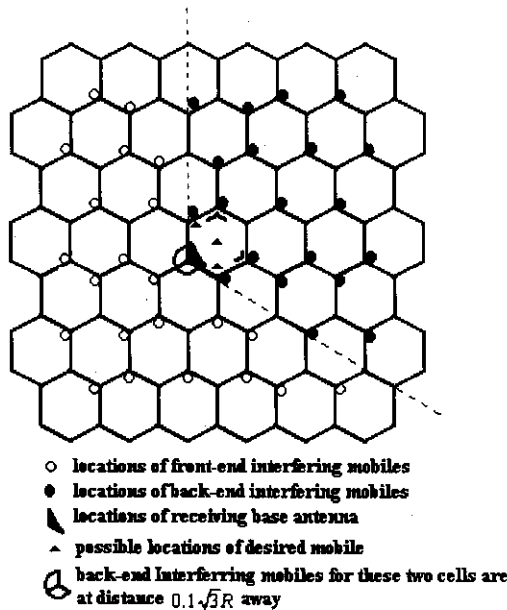


Fig.3. Worst situation mobile-to-base antennas arrangement.

Therefore, their contribution to the total interference is maximum, that is

$$I/S(i, j, \gamma) = \left[\sqrt{3} \left(n_1 - \frac{1}{2} \right) \right]^{-\gamma} \quad (7)$$

where n is an integer coordinate for the worst distances for the cell which has integer coordinates $(n_1, 0)$ with $n_1 > 0$ is equal to $n_1 - 0.5$.

The worst case location of an interfering mobile is taken to be that for which the probability that the mobile is located farther away from the receiving base station is $>99\%$ under a uniform mobile spatial distribution. Hence, worst case location is found to be $0.1\sqrt{3}R$ from the base station.

Base-to-mobile signal-to-interference ratio

It is difficult to select an optimum antenna location for a base station. First the signal strength coverage at some distance about 13km from a base station antenna doesn't exhibit a uniform pattern. This irregular pattern is due to the irregular terrain configuration. Another important aspect is avoiding interference. Therefore, a base station antenna location should consider both its coverage range and its interference with other cells. In a large system all the potential base station location should be considered at the same time, i.e., co-channel and adjacent channel interference. This is because all base station locations chosen to satisfy these two main requirements are closely related among themselves. If one base station is moved to a different location, then all other station locations are affected. Two guidelines for choosing a location are;

1. Not to select a high spot, to avoid an interference with other cells, and avoid weakening signal strength in its own reference cell.
2. To select a low spot but increasing the base station antenna height.

In this proposed model, base-to-mobile communication, the locations of desired and interfering base antennas are assumed fixed, and the receiving mobile can be anywhere inside the reference cell (nominal case) and at a vertex of the reference cell (worst case), while all other base stations are interferes. Therefore, when co-channel interference is considered, the S/I determined at mobiles at the six vertices are the same, while if adjacent channel interference are considered, the S/I are different. Modifying the pervious analysis in equation (4) for the present scenario, then;

$$I/S(i, j, \gamma) = \left\{ 3 \left[(i-d_1)^2 + (i-d_1)(j-d_2) + (j-d_2)^2 \right] \right\}^{-\gamma/2} \quad (8)$$

The remaining calculations for median base-to-mobile S/I measured at a vertex of the reference cell (d_1, d_2) is identical to that for the nominal median mobile-to-base S/I .

Results and Discussion

The purpose of this calculation is to assure that all significant interfering cells are accounted for in this signal – to – interference calculations.

Co-channel and adjacent channel S/I vs tier coverage

Co-channel interference can become a major problem due to reusing an identical frequency channel in different cells. Theoretically, in a hexagonal-shaped cellular system, there are always six co-channel interfering cells in the first tier, as show in Fig 4.

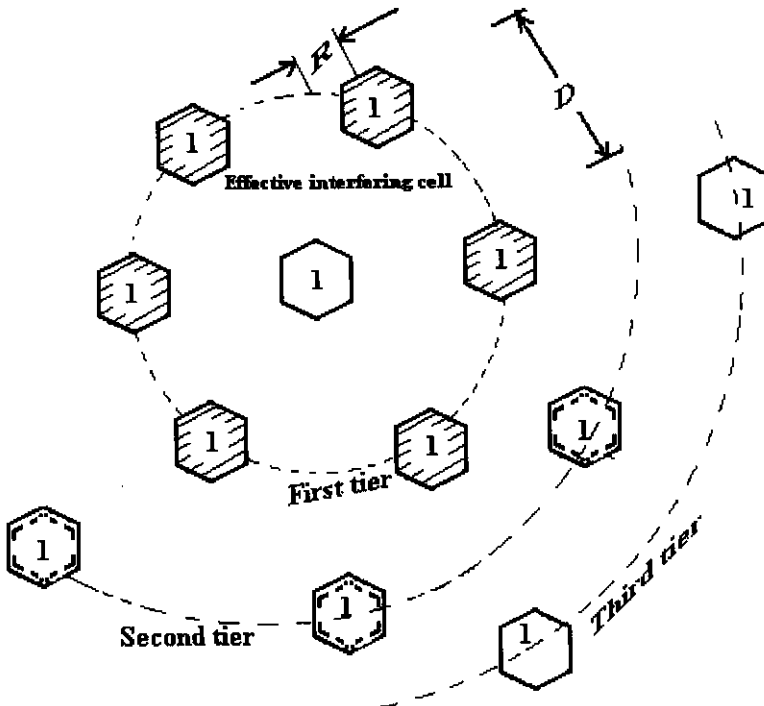


Fig.4. Six effective interfering cells of cell 1.

Co-channel interference can be experienced both at the cell site and mobile units in the reference cell. If the interference is much greater, then the S/I ratio at the mobile units caused by six interfering sites is (on the average) the same as S/I received at the reference cell site caused by interfering mobile unites in the six cells. According to both reciprocity theorem and the statistical summation of radio propagation, the two S/I values can be very close, and can be expressed as [16, p.54].

$$S/I = \frac{R^{-\gamma}}{\sum_{k=1}^{K_I} D_k^{-\gamma}} \quad (9)$$

where γ is determined by the actual terrain environment, and K_I is the number of co-channel interfering cells.

The six co-channel interfering cells in the second tier cause weaker interference, hence, co-channel interference from the second tier of interfering cells may be negligible. Considering interference reduction factor q , yields [17],

$$S/I = \frac{1}{\sum_{k=1}^{K_I} \left(\frac{D_k}{R} \right)^{-\gamma}} = \frac{1}{\sum_{k=1}^{K_I} (q_k)^{-\gamma}} \quad (10)$$

where q is defined as ($q = D/R$), with R as coverage radius, and D is some distance away from the reference cell, where the same frequency may be reused.

The numerical calculations suggest that all significant interfering cells are accounted for, and all typical parameter values are assumed, i.e, propagation exponent γ is 4 and the antenna front-to-back ratio μ is 20dB. Furthermore, interfering signals from cells up to 35 tiers away from the reference cell were included.

Figure 5, shows the nominal mobile-to-base co-channel S/I Vs tier coverage for cluster size $N \leq 13$. The co-channel S/I decreases as the tier coverage increases because interference contributions from more co-cells occur. The decrement in co-channel S/I becomes negligible when the tier coverage increases to exceed a threshold value. Only the first 5 co- cell tiers contributions significantly to the result. Figure 5 shows the calculated results graphically for tier coverage less than 35 and cluster size less than 13. It is clear that some of the cluster sizes have smaller co-channel S/Is than expected. The reason is that the receiving base antenna is located at a vertex of the reference cell such that, for some cluster size, there are more than two first tier co cells located within the front-end of the receiving base station antenna.

It should be mentioned that adjacent channel interference was assumed to be attenuated by the filter characteristics (α and β) in the above numerical calculations considered.

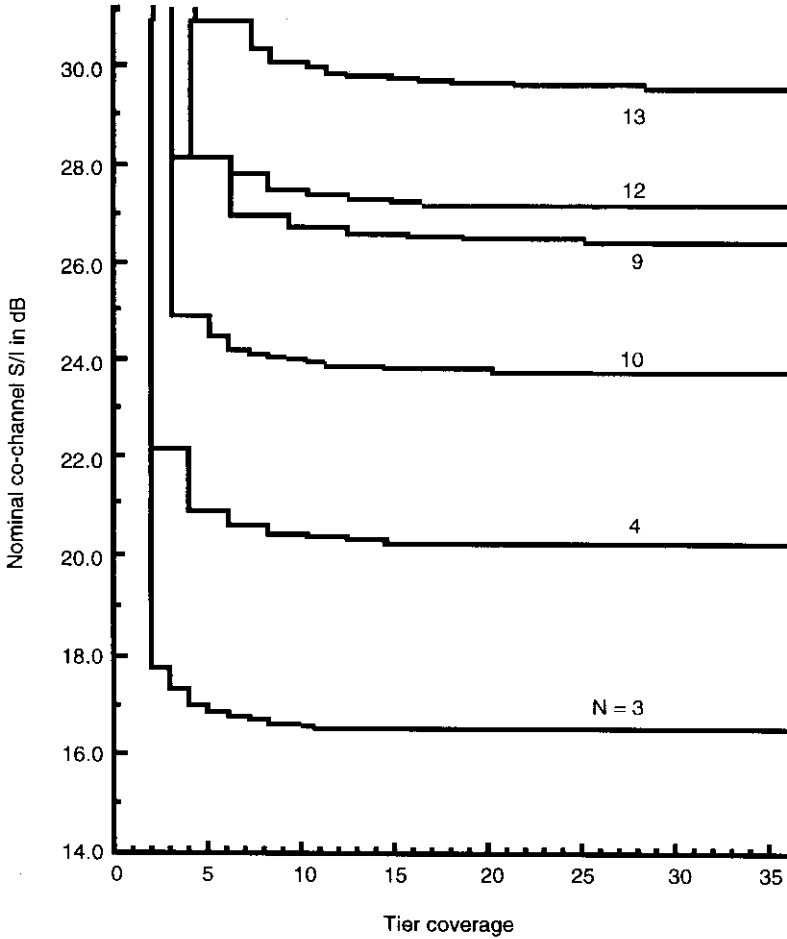


Fig.5. Mobile-to-base S/I Vs tier coverage.

Co-channel and adjacent channel S/I Vs cluster size

Figure 6, shows the mobile-to-base S/I evaluated at the receiving base antenna for cluster size $N \leq 31$, when $\gamma = 4$ and $\alpha = 24$ dB/octave, $\beta = 24$ dB/oct., and $\mu=24$ dB.

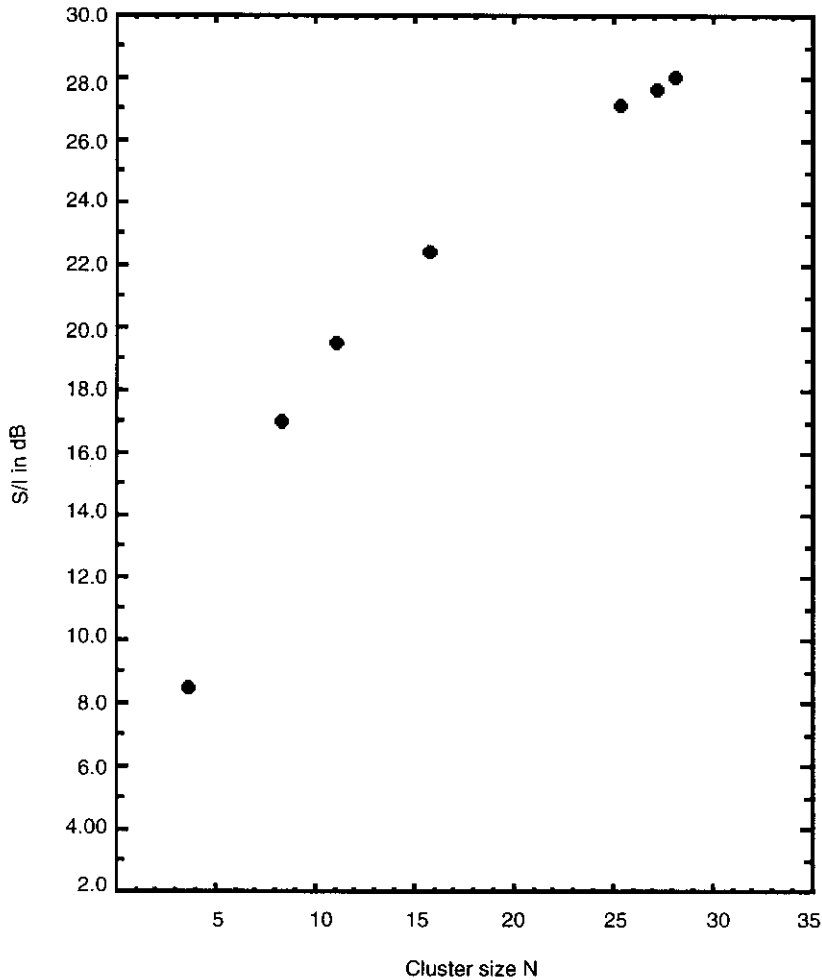


Fig.6. Mobile-to-base S/I Vs cluster size

From figure 6, it is observed that if the cluster size N is increased, the co-channel S/I also increases, because the distance between nearest co cells increases with increasing N , resulting in smaller co-channel interference. Notice that the co-channel S/Is for cluster

size 3, 7, 12, 15, 19, and 27 are significantly below the smooth 6 dB curve due to the effect of first-tier front end co-cells mentioned in the previous section. Referring to Fig.6. Immediately adjacent channel nearest neighboring cells, perform much worse than their corresponding co-channel S/Is, because the desired mobile is many times farther away from its serving base station than is base-end interfering mobile in the neighboring cell served by a different antenna of the same base station on an immediately adjacent channel. For example, with a distance ratio of ten. The received adjacent channel interference level at the base station may be 45 dB higher than the desired signal strength level. Hence, the adjacent channel interference can be very serious for those cluster sizes which cannot avoid assigning immediately adjacent channels in nearest neighboring cells, that is cluster sizes $N \leq 9$. Therefore, for these cluster sizes it is important to avoid the simultaneous use of immediately adjacent channel in nearest neighboring cells.

Co-channel and adjacent channel S/I vs system parameters (α, γ, μ)

Firstly, The filter characteristic α has no effect on co-channel S/Is because the latter include no adjacent interference. Thus, co-channel S/I's are independent of α . However, when α is increased, the adjacent channel interference decreases. Consequently, S/I will increase when α is increased. Further, when α is large enough, system performance will be close to that obtained by considering only the co-channel S/I, because the effect of adjacent channel interference is very small and only the co-channel interference dominates the performance results.

Secondly, The dependency of system performance on the propagation exponent γ is investigated. When γ is large, the transmitter power outputs of all mobiles must be increased in order to be receivable. However, because the desired signal and interfering signals increase to the same power, then the previous analysis is applicable.

Due to the propagation law, the normalized interference from an interference mobile located closer than the desired mobile increases as γ increases since all co-channel interference originates from interfering mobiles farther than the desired mobile at one radius away, the co-channel interference decreases as γ increases. The near-to-far effect is very serious in a highly attenuated environment because the adjacent channel interferers are situated very close to the receiving base station antenna. In general, the effect of adjacent channel interference compared to that of that of co-channel interference becomes more pronounced as γ increases [17].

Thirdly, in mobile to base communications, the three receiving base antenna of the reference cell have different orientation {see Fig.2}, hence, S/Is experienced by these base antennas are different due to adjacent channel interference. When μ is 0dB, i.e, the directional antenna acts like the omni-directional antenna, the resulting co-channel S/Is are smaller than that for systems with base station situated at reference cell centre, due to

the asymmetrical cell structure. The co-channel S/I increases as μ increases since 0.5 to 0.66 of the co-channel interference is attenuated by this ratio. The co-channel S/I tends to limit as μ increases beyond 30dB. This limit corresponds to all co-channel interference coming only from the front-end of the receiving base station antenna. Similarly, in base-to-mobile communications, the co-channel S/I for corner receiving mobiles is smaller than that for the center mobile due to the asymmetrical structure. As μ becomes very large (>30dB), the effect of back-end interference is very small compared to front interference. However, μ is small, back-end interference is greater than a front-end interference.

Conclusions

The foregoing analysis considered provides a simple methodology to obtain relative cellular communications systems performances considering both co-channel and adjacent channel interference under various operating conditions.

A complete calculation of the median mobile-to-base S/I and base-to-mobile S/I in cellular communications systems has been developed, and system performance is evaluated under typical system parameters, i.e, $N = 7$, $\alpha = 36$, $\beta = 24$, $\mu = 20$, $\gamma = 4$. The analytical results deal only with median values, which determine parameters in underlying probabilistic distributions commonly assumed to characterize signal fluctuations in mobile radio.

The model includes the effect of co-channel and adjacent channel interference and it can be concluded from data presented that the difference between an S/I and its corresponding co-channel S/I is substantial in most situations. Another important observation is that, the effect of adjacent channel interference cannot be ignored in general, particularly, in urban environments where the propagation attenuation is high. Furthermore, at some situation, severe near-to-far immediately adjacent channel interference in mobile to base transmission may drastically degrade the S/I system performance. Thus, for some cluster sizes, it is important to avoid the simultaneous use of immediately adjacent at nearest neighboring cells.

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حساب مقدار التداخل في إشارات القنوات المشتركة وفي إشارات القنوات المتناحّة في منظومات الاتصالات الخلوية

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(استلم في ١٧/١٠/١٩٩٨ ؛ وقبل للنشر في ١٠/٤/١٩٩٩)

ملخص البحث. يقدم البحث أسلوباً لحساب نسبة الإشارة إلى التداخل في منظومات الاتصالات الخلوية مزوية التهيّج يقوم على أساس مقدار قدرة إشارة التداخل في الوسط ما بين الجهاز النقال والقاعدة وما بين القاعدة والجهاز النقال بالنسبة للقنوات المشتركة والقنوات المتناحمة وغير المتناحمة. يشتمل النموذج الرياضي على مقاسات المنظومة الأكثر تعلقاً بالموضوع مثل حجم المجموعة العنقودية، خواص المرشح، حيثية الانتشار، شمولية التغطية وكذلك على نسبة الإرسال الأمامي إلى الإرسال الخلفي للهوائي الاتجاهي. كما تناول البحث كلا الاتصاليين الخلويين ما بين النقال والقاعدة وما بين القاعدة والنقال. أثبتت النتائج بأن تأثير التداخل ما بين القنوات المتناحمة بالمقارنة مع التداخل في القنوات المشتركة هو تأثير لا يمكن إهماله عموماً وقد يؤدي إلى ترد خطير للأداء في بيئة تشغيل محددة بالنسبة لتركيّب معين لمعمارية المنظومة.