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# Cochannel Interference Probability of Cellular Mobile Radio Systems in the Environments of Noise and Nakagami Fading plus Lognormal Shadowing

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# 잡음, 나카가미 페이딩과 대수정규 shadowing이 존재하는 환경하에서 셀룰라 이동 무선 시스템의 동일 채널 간섭 확률

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## ABSTRACT

The cochannel interference probability has been estimated both in the environment of Nakagami fading and Gasussian noise and in the environments of Gaussian noise and Nakagami fading plus lognormal shadowing. In noise and Nakagami fading environments, a theoretical analysis has been performed in order to calculate the cochannel interference probability in addition to computer simulation. In the environments of noise and Nakagami fading plus shadowing, only a simulation technique is used due to complexity in analysis. The spectrum efficiency is discussed on each case.

## 要 約

나카가미 페이딩과 가우스 잡음이 함께 존재하는 환경과 가우스 잡음과 나카가미 페이딩 및 대수정규 shadowing이 함께 존재하는 환경의 두가지 환경하에서 동일채널 간섭확률을 구하였다.

잡음과 나카가미 페이딩이 함께 존재하는 환경하에서의 동일채널 간섭확률은 이론 해석에 의해 구하였으며 잡음과 나카가미 페이딩 및 shadowing이 존재하는 환경하에서의 동일채널 간섭확률은 컴퓨터 시뮬레이션에 의해 구하였다. 그리고 각 경우에 대한 스펙트럼 효율을 검토하였다.

결과로부터 동일채널간섭확률은 주파수재사용거리가 작은 경우는 잡음, noise, shadowing의 영향이 복합적으로 나타나지만 주파수재사용거리가 커질수록 path loss의 증가로 인하여 간섭과 전력이 감소되어 희망파의 페이딩 심도와 잡음에 의해 좌우된다는 것을 알 수 있었다.

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From the results, we found that cochannel interference probability at a small reuse distance is affected by noise and fading plus lognormal shadowing but, at a large reuse distance, fading severity of desired signal and noise dominate the cochannel interfernce probabilty because path loss makes the power of interferers weak.

## Ⅰ. Introduction

The cellular systems use the same frequency in distinct cells in order to increase the spectrum efficiency. But the closer is the channel reuse distance for spectrum efficiency, the larger is the amount of cochannel interference (interference originated by the cells using the same channel). And the required performance of the systems connot be obtained.

Meanwhile, due to ground irregularity and generally low antenna elevations, the direct path between transmitter and receiver can be obstructed in the mobile radio channel.(1) This is the main cause of shadowing effect in median signal level. In addition, fading caused by mutipath propagation superimposes on the shadowing.

As a received signal level fluctuates due to many factors, the amount of interference for one specific location is measured not by a fixed value but by probability. The limiation in distance for reusing frequency channel can be determined by the cochannel interference probability. But in the high-capacity mobile radio systems, the transmission quality of a system is strongly dependent on thermal noise as well as chchannel interference.(2) Therefore, to achieve a satisfactory frequency channel assignment plan, it is necessary to investigate the cochannel interference probability in the presene of fading, shadowing and thermal noise.

Most of the previous papers, [3]-[13], have focused on only the cochannel interference in the measurement of the system performance. Only one paper, [2], investigated the effect of the Gaussian noise on the cochannel interference probabbility. But it assumed that both the desired signal and undesired cochannel interferers are subjected to Rayleigh fading. Such an assumption is invalid in the case that the received signal contains direct wave or in less severe fading environments such as suburban, rural and open area. The Rayleigh fading model is confined to a received signal composed of multipath signals coming from all directions caused by reflection, diffusion and diffraction. In order to avoid those limits and model different fading envirommnents, this paper evaluates the cochannel interference probability of mobile radio systems operating in Nakagami fading and Gaussian noise by using the mathematical model proposed in [2]. As Nakagami fading model includes the Rayleigh distribution as a special case and approximates the Rician distribution which fits the direct wave existing envirommnents, this analysis can give more versatility in comparison with teh case of the Rayleigh fading. Shadowing effect, which was not handled in [2] on account of complexity in analysis, is accounted for by simulation in this paper. The spectrum efficiency is computed in Nakagami fading and noise channels and in Nakagami fading plus shadowing and noise channels respectively.

## Ⅱ. Characteristics of Cellular Mobile Radio Channel

The predictions made in this paper are based on a model of propagation between a base station and a mobile station which has four main aspects : fading, shadowing, Gaussian noise and path loss.

As a vehicle moves through the servide area, the received signal envelope R fluctuates rapidly due to multipath propagation and wave interference. In most case, the received signal envelope is assumed to fluctuate with Rayleigh probability density function.(3) But this assumption is valid only for the case that a received signal is composed of multipath waves uniformly comming from all directions because of reflection, diffusion and diffraction. However, it is a common case that exist diffraction waves includes stationary component caused by the rooftop of a building or a roadside tree in urban locations. In the event there are fixed scatters or signal reflectors in the medium, in addition to the randomly moving scatters, the signal envelope can no longer be modeled as having Rayleigh p.d.f. In those cases, Nakagami distribution or Rician distribution is more fit to the fading model rather than Rayleigh distribution.(10),(12) In this paper, Nakagami fading model is to be used for the following reasons. First, the Nakagami fading model is one of the most versatile. The Nakagami fading (m-distribution)(13) has a generalized distribution that can model different fading environments according to an index, m, as shown Fig. 1. Second, it has greater flexibility and accuracy in matching some experimental data than the Rayleigh, log-normal, or Rician distribution. Third, Nakagami distribution takes the Rayleigh distribution as a special case and also approximates the Rician distribution.(11),(12)

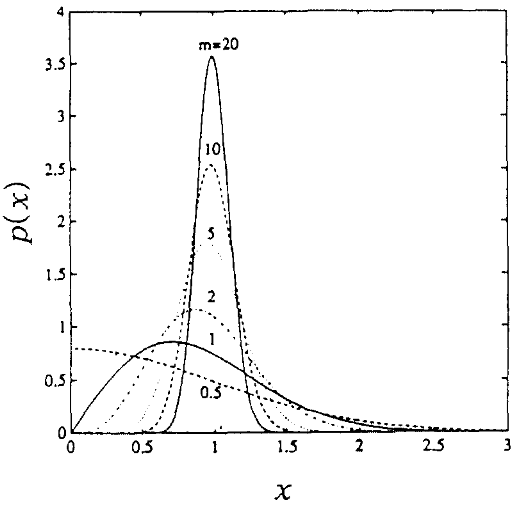


Fig. 1. Nakagami distribution p.d.f.

Shadowing of the radio signal by building and hills leads to gradual changes in local mean level as a vehicle moves, with the result that the local mean $\overline{R}$ is lognormally distributed within area, say 500[m] across. The severity of the shadowing is represented by dB spread, $\sigma$ dB. The parameter $\sigma$ is typically between 6 dB and 12 dB in practical channel.(3),(11) The shadowings of the desired and interfering signals are assumed to be independent in this paper.

Gaussian distribution is used here for representing the noise variation. A more realistic noise model might be an additive mixture of Gaussian noise and non-Gaussian impulsive noise.(2),(14) In order to avoid complexity in analysis, only the influence of Gaussina noise is considered.

## III. Cochannel Interference Probability in Nakagami Fading plus Noise Channel

The cochannel interference probability may be defined as

$$F(CI) \equiv \sum_{L} F(CI \mid L) F_{L}(L) \tag{1}$$

Here $F_l(L)$ is the probability of L cochannel interferers being active, $F(CI|L)$ is the corresponding conditional cochannel interference probability that the interference power exceeds the desired signal power divided by an appropriate power protection ratio Q. Considering the effect of thermal noise, $F(CI|L)$ can be defined as

$$F(CI \mid L) \equiv \text{Prob.}\{ p_d / p_u < Q \} \tag{2}$$

where $p_d$ is the instantaneous power of the desired signal, $p_u$ is the undesired power which is composed of white Gaussian noise power and joint interference power from L active channel.(3),(4),(7),(15)

In a Nakagami fading environment, the Nakagami distribution characterizes the signal magnitude statistically. The desired signal power, S (in watt per meter), is then a gamma distributed r.v.

with probability density function, f(S), given by (11)

$$f(S)=\left(\frac{m}{\Omega}\right)^{m}\frac{S^{m-1}}{\Gamma(m)}\exp\left(-\frac{m}{\Omega}S\right) \tag{3}$$

where m≧0.5 and $\Omega(=\overline{S^2})$ is the average power of the desired signal. The constant m is called fading index and $\Gamma(\cdot)$ is the gamma function. The signal power distribution for a Rayleigh fading channel is obtained by putting m=1. The less severe fading conditions are modeled by lager value of the fading index m. And the nonfading case corresponds to m=∞.(13)

Assume that there are L independent identically distributed (i.i.d.) interferers having the same average power. This assumption is a resonable one when all interferers are at approximately the same distance from the mobile station. Then the independent instantaneous interferer phasors add together to produce the resultant instantaneous interferer. Since the interferers are statistically independent, the short-term power of the resultant interferer, I, can be written as

$$I=I_1+I_2+\cdots\cdots+I_L \tag{4}$$

where $I_i$ (i=1, 2, ⋯, L) is a r.v. representing the short-term power of the $i_{th}$ interferer. In a Nakagami fading environment, $I_i$ is a gamma distributed r.v. whose p.d.f. is given by (3) with average power Y and fading index m′. Using Laplace transform, the p.d.f. of y is found to be(11), (12)

$$f_I(y)=\left(\frac{m'}{Y}\right)^{m'L}\frac{y^{m'L-1}}{\Gamma(m'L)}\exp\left(-\frac{m'}{Y}y\right)\quad (y>0) \tag{5}$$

Assuming the noise comes from a stationary Gaussian random process, then the p.d.f. of the envelope is a Rayleigh function given by(2)

$$f_{a_n}(a_n)=\frac{a_n}{N_r}\exp\left(-\frac{a_n^2}{2N_r}\right) \tag{6}$$

where $a_n$ is the random noise amplitude and $N_r$ is the mean noise power. The corresponding p.d.f. of the instantaneous noise power N is

$$f_N(N)=\frac{1}{N_r}\exp\left(-\frac{N}{N_r}\right),\qquad (N=P_u-y) \tag{7}$$

Using Eqs.(3)-(7), F(CI|L) is obtained as

$$F(CI|L)=\int_0^{\infty}dP_u\int_0^{QP_u}dS\int_0^{P_u}\left(\frac{m}{\Omega}\right)^{m}\frac{S^{m-1}}{\Gamma(m)}\exp\left(-\frac{m}{\Omega}S\right)$$
$$\cdot\left(\frac{m'}{Y}\right)^{m'L}\frac{y^{m'L-1}}{\Gamma(m'L)}\exp\left(-\frac{m'}{Y}y\right)\frac{1}{N_r}$$
$$\cdot\exp\left(-\frac{P_u-y}{N_r}\right)dy \tag{8}$$

Eq.(8) is solved as follows

$$F(CI|L)=\frac{1}{\Gamma(m)}\left(1-\frac{CNR}{m'CIR}\right)^{-m'L}\cdot\Big[\Gamma(m)\left(1+\frac{CNR}{mQ}\right)^{-m}$$
$$-\underline{\sum_{k=0}^{m'L-1}CNR\cdot(m'CIR-CNR)^{k}\cdot\Gamma(m+k+1)\cdot Z^{m+k+1}}$$
$$\cdot{}_2F_1(1,\ m+k+1\ :\ m+1\ ;\ Z)\Big],$$

where, (9)

$$Z=\left(\frac{m'CIR}{mQ}+1\right)^{-1}$$

and CNR is carrier to noise power ratio (CNR=Ω/Nr) and CIR is carrier to interference power ratio (CIR=Ω/Y). When only interferers signals from the nearest neighboring six cochannel cells are considered, where the blocking probability B and the number of channels $n_c$ are the same in all cells, $F_L(L)$ can be written as(11)

$$F_L(L)=\binom{6}{L}B^{L/n_c}(1-B^{1/n_c})^{6-L}\quad (L=0,\ 1,\cdots\cdots,L) \tag{10}$$

And $F_L(L)$ can also be expressed in terms of carried traffic $a_c$ per channel(16), (17)

$$F_L(L)=\binom{6}{L}a_c^L(1-a_c)^{6-L} \tag{11}$$

where $a_c=T_c/n_c$ and $T_c$ is the carried traffic per cell. The cochannel interference probability can

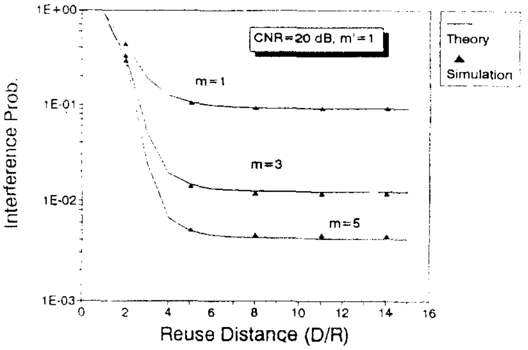


Fig. 2. Cochnnel interference probability of a Nakagami fading signal in the presence of a single Nakagami interferer and noise as a fuction of reuse distance for CNR=20[dB], m'=1

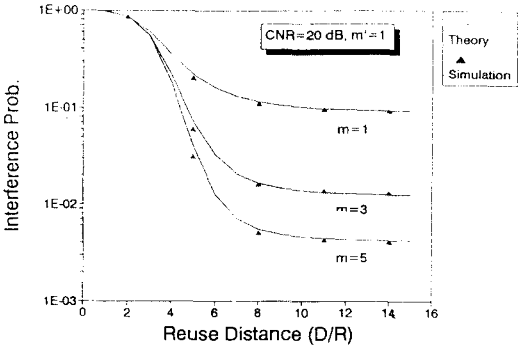


Fig. 3. Cochnnel interference probability of a Nakagami fading signal in the presence of a random number of Nakagami interferers and noise as a fuction of reuse distance for Q=10[dB], B=0.02, $a_c$=5[erl.] $n_c$=10, CNR=20[dB], and m'=1.

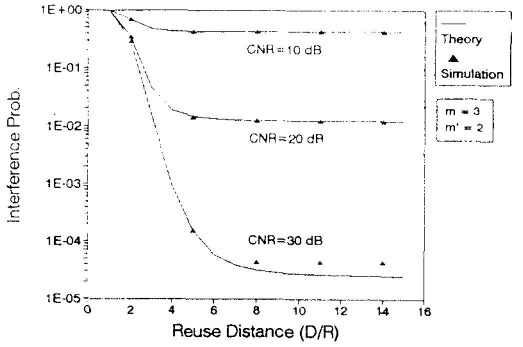


Fig. 4. Cochannel interference probability versus reuse distance with CNR as parameter for Q=10[dB], B=0.02, $a_c$=5[erl.] and $n_c$=10.

be calculated with a random number of interferers using Eq.(1), Eq.(9) and Eq.(10). The cochannel interference probability $F(CI)$ in Nakagami fading and noise channel is, then, found as

$$F(CI)=\left(1+\frac{\mathrm{CNR}}{mQ}\right)^{-m}\cdot F_L(0)+\sum_{L=1}^{n} F(CI|L)\cdot F_L(L) \quad (12)$$

In the mobile environment, the propagation loss is inversely proportional to distance to the fourth power.(11) This is an expression of loss in dB, and it is given as

$$Loss \propto \frac{1}{d_{km}^{3.52}} \quad (13)$$

Here, in order to reduce complexity, the approximate value of $d_{km}^{4}$ is used instead of $d_{km}^{3.52}$ in Eq.(13). Using the fourth power law, the carrier to interference power ratio has the following ralationship.

$$CIR=\frac{1}{L}(R_u)^4 \quad (14)$$

where $R_u$ is the reuse distance defined as the ratio of the distance between cochannel cell centers and radius of a cell, R.(2),(18),(19)

$$R_u \equiv \frac{D}{R} \quad (15)$$

Using Eq.(12), Eq.(14) and Eq.(15), the cochannel interference probability at each frequency reuse distance can be calculated in the presence of Nakagami fading and Gaussian noise.

Fig. 2, Fig. 3, and Fig. 4 show the validity of the theoretical analysis by comparing with the value computed by computer simulation. Fig. 2 and Fig. 3 depict cochannel interference probability versus normalized reuse distance with the fading index m of the desired signal when the fading index of the interferer, m′ is fixed to 1. It is known that as the fading index increase, i.e., the severity of the fading decreases, cochannel interference probability decreases at the same reuse

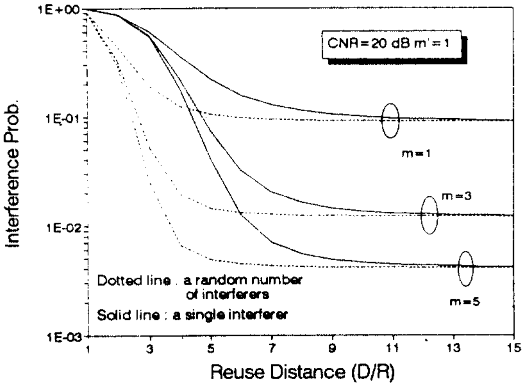


Fig. 5. Cochannel interference probability versus reuse distance with the fading index of wanted signal, m, as a parameter for Q=10[dB], CNR=20 [dB], B=0.02, $a_c=5$[erl.] and $n_c=10$. (Dotted line : a random number of interferers, Solid line : a single interferer)

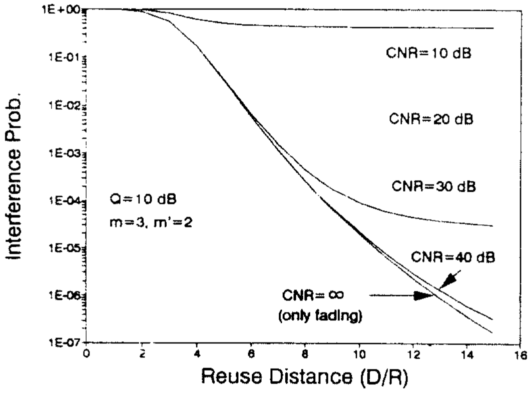


Fig. 6. Cochannel interference probability versus reuse distance with CNR as a parameter for Q=10 [dB], B=0.02, $a_c=5$[erl.] and $n_c=10$.

distance. Fig. 4 represents the cochannel interference probability versus reuse distance with CNR as a parameter.

Cochannel interference probability has been calculated for Q=10 dB, CNR=20 dB and m'=1 and is shown in Fig. 5 as a funcion of reuse distance with the fading index of the desired signal and the number of interferers as parameters. Fig. 5 shows that the number of the interferer has an effet on the cochannel interference probability at small reuse distances but the cochannel interference probability at large reuse distances is mainly subjected to the noise because of the relatively small power sum of interferes.

Fig. 6 shows cochannel interference probability versus reuse distance with CNR as a parameter. In Fig. 6, for large CNR, cochannel interference probability becomes approximately equal to the case of fading only which corresponds to $N_r \rightarrow 0$.

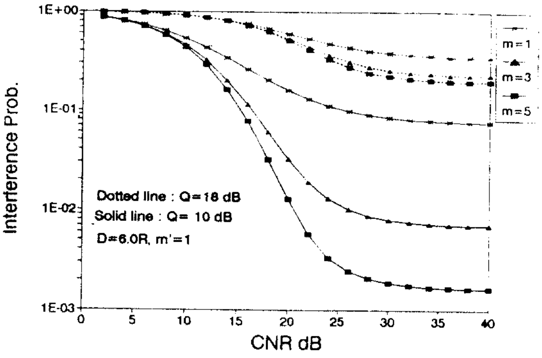


Fig. 7. Cochannel interference probability versus carrier to noise ratio (CNR) with the fading index and Q as parameters for D=6.0R, B=0.02, $a_c=5$[erl.] and $n_c=10$.

Fig. 7 represents the cochannel interference probability versus CNR with the power protection ratio Q and fading severity as parameters. It is known that the fading index has more influence on the cochannel interference probability when cochannel interference probability for Q=10 dB is compared with that for Q=18 dB and that cochannel interference probability for large CNR becomes equal to the value of the fading case.

## Ⅳ. Cochannel Interference Probability in Nakagami Fading plus Lognormal Shadowing and Noise Channel

In the previous section, the equation of the cochannel interference probability has been derived when the desired signal and interferers undergo Nakagami fading and noise without shadowing. In addition, the theoretical results are compared with the values of computer simulation.

In this section, the cochannel interference probability will be investigated by using computer simulation under the condition that the desired signal and the interferers are subjected to Nakagami fading plus shadowing and noise.

### 1. Considerations for shadowing effect

Under shadowing, the mean power level of the desired signal, Ω, and the mean power level of an interferer, $Y_i$, have lognormal distributions.(10),(11),(18) That is,

$$f_{shad}(\Omega_d)=\frac{1}{\sqrt{2\pi}\,\sigma_s}\exp\left(-\frac{(\Omega_d-\Omega_{nd})^2}{2\sigma_s^2}\right) \qquad (16)$$

$$f_{shad}(Y_d)=\frac{1}{\sqrt{2\pi}\,\sigma_I}\exp\left(-\frac{(Y_d-Y_{nd})^2}{2\sigma_I^2}\right) \qquad (17)$$

where $\Omega_d$ and $Y_d$ are the logarithms of the mean power level of the desired signal, $\Omega$, and the interferer, $Y_i$, respectively. The parameters $\sigma_s$ and $\sigma_I$ are called dB spread and typically have values between 6 dB and 12 dB depending on the severity of the shadowing.(11) Since shadowing is a local phenomenon, this paper assumes that $\sigma_s$ is equal to $\sigma_I$.

In order to calculate the cochannel interference probability with i.i.d. L interferers in the presence of fading plus shadowing, an (L+1)-fold iterative integral is necessary.(11) As the numerical (L+1)-fold integration has inherent unstability, round off, and verification question, computer simulations are used for the evaluation of cochannel interference probability in the Nakagami fading plus shadowing and noise channel.

### 2. Simulation technique

When a user receives service from a desired base station, the instantaneous power at that position is modeled by

$$S=P(m)-L(d_s)+X_s \quad \text{dBm} \qquad (18)$$

where P(m) is the transmitter power dBm which follows gamma distribution representing the effect of Nakagami fading with index m, L($d_s$) is the path loss dB, $d_s$ is the distance between the wanted base sation and the user, and $X_s$ is the random shadowing term.

The expression for the instantaneous power of cochannel interfering base station is similar to that of the desired serving base station. The instantaneous power from the $j_{th}$ unwanted base station is

$$I_i=P(m')-L(d_i)+X_i \quad \text{dBm} \qquad (19)$$

$d_i$ is the distance from the user to $j_{th}$ cochannel interfering base station, m′ is the index of fading severity which suppresses the interference power level, and $X_i$ is the random shadowing term. When the hexagonal cell is assumed, the total interfering power at the user's position is found as

$$I_{tot}=10\log_{10}\left(\sum_{m=1}^{L}10^{I_m/10}\right) \text{dBm}, \quad (0\leqq L\leqq 6) \qquad (20)$$

where L is the number of cochannel interferers being active and varies with Binomial distribution.

Cochannel interference is occurred under the following condition.

$$\frac{S}{(N+I_{tot})}\leqq Q \qquad (21)$$

where noise power N is generated using the routine yielding random values deviated exponentially as the p.d.f. of the instantaneous noise power is found as Eq.(7).

In this paper, Monte Carlo simulation techniques[20] are used to compute the cochannel interference probability by repeatedly calculating and tabulating values of the wanted signal power ($S$), the total cochannel interference power ($I_{tot}$), and noise power ($N$). About 100,000 samples of $S$, $I_{tot}$, and $N$ are caculated per a simulation run. Fig. 8 represents the flow chart for the simulation program.

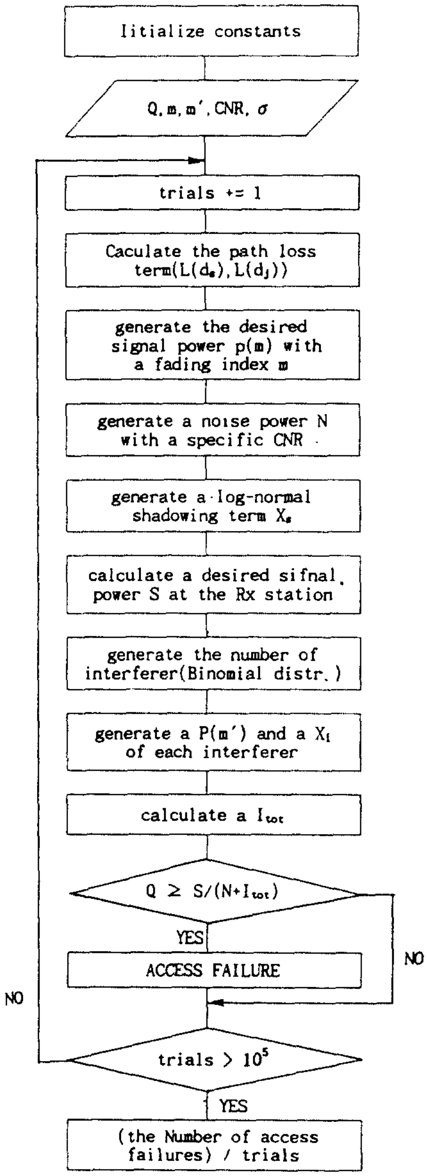


Fig. 8. Flow chart for the simulation.

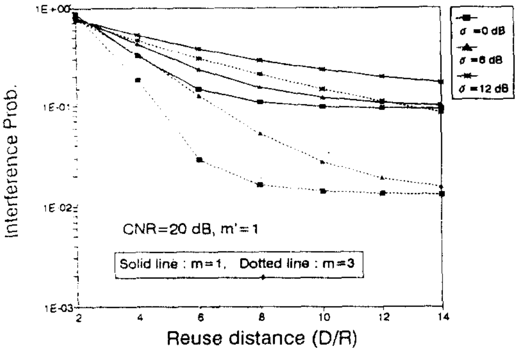


Fig. 9. Cochannel interference probability of a Nakagami fading signal in the presence of Nakagami interferers. The fading indices of the desired signal and interferers are m and m′, respectively. The desired signal and interferers undergo noise with CNR=20[dB] and lognormal shadowing with $\sigma=0$[dB], $\sigma=6$[dB], and $\sigma=12$[dB].

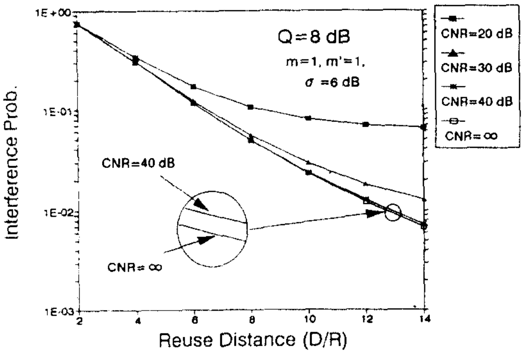


Fig. 10. Cochannel interference probability versus reuse distance in the environments of noise and Nakagami fading plus shadowing for Q=8[dB], dB spread $\sigma=6$[dB].

Fig. 9 shows the cochannel interference probability of desired signal experiencing Nakagami fading in the presence of a random number of interferers and noise, as a function of the reuse distance. All signals are subjected to lognormal shadowing. These results are obtained by com-

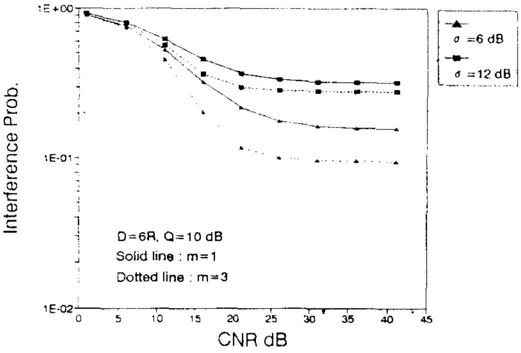


Fig. 11. Cochannel interference probability versus CNR with the fading index and $\sigma$ as parameters in the presence of noise and Nakagami fading plus shadowing for Q=10[dB], D=6.0R.

puter simulation. This figure shows that the simulation results for $\sigma=0$ dB are equal to the theoretical values obtained in the environments of Nakagami fading plus noise. Fig. 9 shows that the shadowing has a strong influence on the cochannel interference probability in the less severe fading environment, e.g. m=3, m′=1, than that in Rayleigh fading (m=1, m′=1) environment.

Fig. 10 shows the cochannel interference probability versus reuse distance for Q=8 dB, $\sigma=6$ dB, m=1 and m′=1 with CNR as a parameter. It is confirmed that if CNR goes to infinity, the effect of noise can be ignored and then the value of cochannel interference probability becomes equal to that for fading plus shadowing channel.

In Fig. 11, as CNR increase, the cochannel interference porbability converges on some values more fast for large $\sigma$ rather than for small $\sigma$. This indicates that noise may have much effect on the cochannel interference probability for small $\sigma$.

## Ⅴ. Spectrum Efficiency

When $T_c$ denotes carried traffic per cell, $n_c$ the number of channels per cell, $W$ bandwidth per channel, $C$ cluster size, and $s$ a unit cell area, spectrum efficiency for cellular systems is defined as (2), (1), (21)

$$E_s \equiv \frac{T_c}{n_c W C s} \text{ erlang / MHz / km}^2 \qquad (22)$$

Carried traffic is obtained by

$$T_c \equiv A(1-B) \qquad (23)$$

where A is the offered traffic per cell in erlang and B is the blocking probability which is determined using the Erlang B formula.

The cells are assumed to form a cluster of size C, located around a reference cell and repeated around each of its cochannel cells. However, the exact shape of a valid cluster need not be precisely specified.[1], [18], [19] The cluster size takes the form

$$C = i^2 + ij + j^2 \qquad (24)$$

with integer i and j.

The reuse distance and the number of cells per cluster are related by

$$R_u = (3C)^{1/2} \qquad (25)$$

From the Eq.(22) and Eq.(25), the relation between reuse distance $R_u$ and spectrum efficiency $E_s$ can be deduced. Therefore, the cochannel interference probability calculated in the section Ⅲ and the section Ⅳ can be obtained as a function of spectrum efficiency.

Fig. 12 shows the cochannel interference probability versus spectrum efficiency with the fading index of the desired signal and CNR as parameters for $a_c$=0.5 Erl./channel, B=0.02, m′=1 and Q=10 dB in the presence of Nakagami fading plus noise. As expected for a given value of CNR, the cochannel interference probability is lower for less severe fading. In Fig. 12, the noise may increase the cochannel interference probability when the value of CNR is small. For example, Table 1 shows the spectrum efficiency required to achieve a cochannel interference probability of 0.1 for some cases.

**Table 1.** Spectrum efficiency to achieve cochannel interference probability of 0.1 for $a_c$=0.5 Erl./channel, B=0.02, W=25 kHz in the presence of Nakagami fading plus noise.

| m | m′ | Spectrum Efficiency erlang /MHz /km$^2$ | |
|---|---|---|---|
| | | CNR=20 dB | CNR=40 dB |
| 1 | 1 | about 0.6 | about 2.45 |
| 3 | 1 | about 2.7 | about 4.04 |

**Table 2.** Spectrum efficiency to achieve cochannel interference probability of 0.1 for $a_c$=0.5 Erl./channel, B=0.02, CNR=20 dB, Q=10 dB, W=25 kHz in the presence of Nakagami fading plus shadowing and noise.

| m | m′ | Spectrum Efficiency erlang /MHz /km$^2$ | | |
|---|---|---|---|---|
| | | only fading($\sigma$=0 dB) | $\sigma$=0 dB | $\sigma$=12 dB |
| 1 | 1 | about 0.6 | about 0.26 | about 0.0 |
| 3 | 1 | about 2.7 | about 1.4 | about 0.35 |

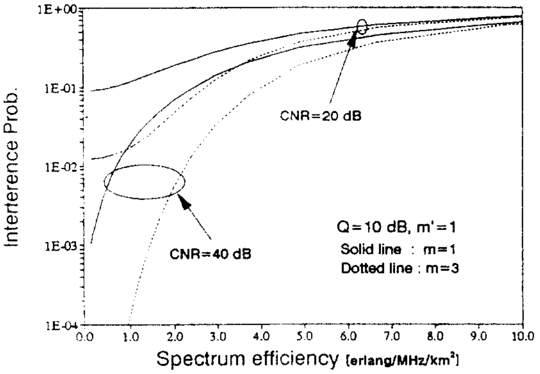


Fig. 12. Cochannel interference probability versus spectrum efficiency in the environments of noise and Nakagami fading for B=0.02, $a_c$=5[erl.] $n_c$=10, and W=25[kHz].

Fig. 13 depicts the cochannel interference probability versus spectrum efficiency with dB spread, $\sigma$, as a parameter. We can find from Fig. 13 that the shadowing effect makes the cochannel interference probability increases at the same spectrum efficiency.

Table 2 compares the spetrum efficiency to achieve the cochannel interference probability of 0.1 in different fading environments with $\sigma$=0 dB, $\sigma$=6 dB and $\sigma$=12 dB for Q=10 dB and CNR=20 dB.

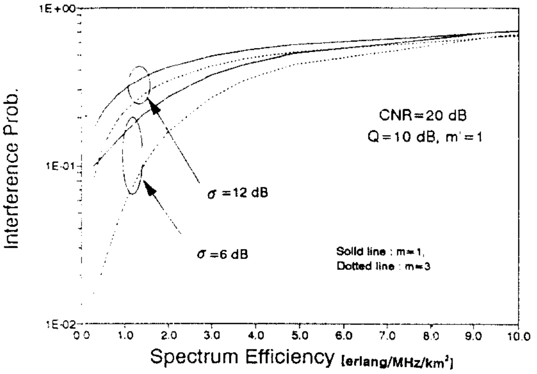


Fig. 13. Cochannel interference probability versus spectrum efficiency with dB spread as a parameter in the environments of noise and Nakagami fading plus shadowing for CNR=20[dB], B=0.02, $a_c$=5[erl.] $n_c$=10, and W=25[kHz].

## Ⅵ. Conclusions

In this paper, the cochannel interference probability has been estimated both in Nakagami fading and Gaussian noise channels and in the environments of the noise and Nakagami fading plus lognormal shadowing. The theoretical analysis has been performed in order to calculate the cochannel interference probability in noise and Nakagami fading channels. The results have been confirmed by computer simulation. In the environments of noise and Nakagami fading plus shadowing, cochannel interference probability is calculated by computer simulation. The spectrum efficiency is also computed in each case.

From the results it can be concluded that :

1) Cochannel interference probability has a limited value at a reuse distance by adding a noise term. After that point, cochannel interference probability is hardly changed even though reuse distance is farther increased.

2) As a reuse distance is fixed to a value and CNR is made to increase, the fading severity of the desired signal has more influence on the cochannel interference probability for a small power protection ratio Q than for a large Q.

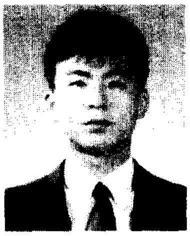
3) In the case of severe fading(e.g. m=1), the effect of lognormal shadowing is relatively reduced and cochannel interference probability mainly depends on fading and noise.

4) While cochannel interference probability at a small reuse distance is affected by noise and fading plus lognormal shadowing, fading severity and noise dominate the cochannel interfernce probabilty at a large reuse distance because path loss makes the power of interferers weak.

## References

1. W. R. Braun, "A physical mobile radio channel model", *IEEE Trans. Veh., Technol.*, vol. VT-40, pp. 472-482, May 1991.
2. A. Kegel, W. Hollemans, and R. Prasad, "Performance analysis of interference and noise limited cellular land mobile radio", *Proc. 41st Vehicular Technology conference*, St. Louis, MO, pp. 817-821, May 1991.
3. R. C. French, "The effect of fading and shadowing on channel re-use in mobile radio", *IEEE Trans. Veh. Tech.*, vol. VT-28, pp. 171-181, Aug. 1979.
4. R. Prasad and A. Kegel, "Improved assesment of interference limits in cellular radio performance", *IEEE Trans. Veh. Tech.*, vol. VT-40, pp. 412-419, May 1991.
5. K. W. Sowerby and A. G. Williamson, "Outage probabilities in mobile systems suffering cochannel interference", *IEEE J. Select. Areas Commun.*, vol. SAC-10, pp. 516-522, Apr. 1992.
6. R. C. Bernhardt, "Macroscopic diversity in frequency reuse radio systems", *IEEE J. Select. Areas Commun.*, vol. SAC-5, pp. 862-870, Jun. 1987.
7. A. Safak and R. Prasad, "Effect of correlated shadowing signals on channel reuse in mobile radio systems", *IEEE Trasn. Veh. Tech.*, vol. VT-40, pp. 708-713, Nov. 1991.
8. R. H. Muammar, "Co-channel interference in microcelluar mobile radio system", *Proc. Vehicular Technology Society 42nd VTS conference*, pp. 198-203, 1991.
9. R. Prasad and A. Kegel, "Performance evaluation of microcellular systems with shadowed Rician/Rayleigh faded multiple co-channel interferers", *Proc. Vehicular Technology Society 42nd VTS conference*, pp. 427-430, 1991.
10. 奧井重彦, "m 分布 フェジング 通信路における周波數再使用距離" (日本) 電子情報通信學會論文誌, vol. J74-B-Ⅱ, no. 5, pp. 332-335, 1991.
11. A. A. Abu-Dayya, N. C. Beaulieu, "Outage probabilties of cellular mobile radio systems with multiple Nakagami interferers", *IEEE Trans. Veh. Tech.*, vol. VT-40, pp. 757-768, Nov. 1991.
12. Y.-D. Yao, A. U. H. Sheikh, "Investigation into cochannel interference in microcellular mobile radio systems", *IEEE Trans. Veh. Tehc.*, vol. VT-41, pp. 114-123, May 1992.
13. M. Nakagami, "The m distribution-a general formula of intensity distribution of rapid fading"-*Statical Methods of Radio Wave Propagation*, ed. W. C. Hoffman, Pergamon Press, 1960.
14. N. J. Boucher, *The Cellular Radio Handbook*. Quantum Publishing, Inc., 1990.
15. R. Prasad and A. Kegel, "Spectrum efficiency of microcelluar systems", *Proc. 41st Vehicular Technology conference*, St. Louis, MO, pp. 357-361, May 1991.
16. Y. Nagata and Y. Akaiwa, "Analysis for spectrum efficiency in single cell trunked and cellular mobile radio", *IEEE Trans. Veh. Technol.*, vol. VT-35, pp. 100-113, Aug. 1987.
17. K. Daikoku and H.Ohdate, "Optimal channel reuse in cellular land mobile radio systems", *IEEE Trans. Veh. Technol.*, vol. VT-32, pp. 217-224, Aug. 1983.
18. W. C. Y. Lee, *Mobile Communications Design Fundamentals*. Howard W. Sams & Co, 1986.

19. W. C. Y. Lee, *Mobile Celluar Telecommunications Systems.* McGraw-Hill Book Co., 1989.
20. M. C. Jeruchim, P. Balaban, and K. S. Shanmugan, *Simulation of Communication Systems.* Plenum Press. 1992.
21. Y. Nagata and Y. Akaiwa, "Analysis for spectrum efficiency in single cell trunked and cellular mobile radio", *IEEE Trans. Veh. Tech.*, vol. VT-35, pp. 100-113, Aug. 1988.



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