Outage Performance and Derivation due to Adjacent Channel Interference

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***Abstract*—This paper describes the mathematical formula derivation method of the outage probability and compares the mathematical formula with statistical Monte-Carlo (MC) simulation results. The outage probability is the factor considered in the adjacent channel interference (ACI) impact between a victim terminal station and multiple interfering terminal stations. For protection of a victim terminal station from harmful interference, we would calculate the out of band emission limit of an interfering terminal station, too. The distribution of multiple interfering terminal stations within a cell follows the Poisson point process. The propagation model is a composite median pathloss and shadow fading with Log-normal distribution. Outage probability is obtained and evaluated with various parameters based on Long Term Evolution (LTE) Time Division Duplex (TDD) terminal stations.**

***Keywords*—mask; interference; block; channel; adjacent**

I. INTRODUCTION

Due to the increase of the rapid data transmission with high capacity and the scarcity of available frequencies, the capacity performance of a mobile communication system may be reduced. When multiple terminal stations are located within the close proximity and the frequency bands are assigned in the adjacent bands like the reverse FDD (Frequency Division Duplex) assignment, the harmful interference among terminal stations may happen. Due to the aggregate interference of interfering terminal stations, out of band emission of an interfering terminal station should be suppressed as lower level than the reference limit level of the block edge mask of a terminal station for the protection of a victim station. The calculation of the block edge mask is still an open research issue. Both a deterministic minimum coupling loss (MCL) and a stochastic approach based on the Monte-Carlo (MC) simulation have been suggested in [1]. MC simulation is a computerized mathematical scheme and provides the decision-maker with a range of possible outcomes and the probabilities it will occur for any choice of action. The result generated is a probability of the interference or the outage. MC approach is a statistical scheme, which is to distribute a victim terminal station amongst a population of interferers. MC method is capable of modeling highly complex systems including a cellular system like LTE. MCL approach is relatively straight forward. MCL method is capable of modeling only a single interferer to a single victim station.

Statistical distribution of the aggregate ACI from multiple interferers has been studied in relation to dynamic spectrum sharing on the legacy radio systems and the interference protection [2]-[3]. Log-normal distribution is used to approximate the probability distribution function (PDF) of aggregate interfering signals received at the center from multiple terminal stations distributed uniformly in an annual region with inner radius and outer radius [2]. Log-normal approximation does not match well due to a large difference of the interference received both from near and far away multiple terminal stations, when outer radius is several ten times larger than inner radius. In the other hands, the Log-normal approximation does work well for a system with an exclusive region such as the cognitive radio [3].

In this paper, we derive the mathematical formula of the outage probability optimized in the approximation for fitting with the coexistence of terminal stations of a small radius and in the LTE TDD system. This formula is capable of calculating the block edge mask and out of band limit for the adjacent channel sharing between operators or terminal stations. The outage probability means the total outages counted as the calculated signal reception level is lower than the reference threshold of the signal reception level. To offer practical protection limit from the aggregate interference, the derived equation's analytic results are in good agreement with the Monte-Carlo simulation ones.

II. SCENARIO

Let us consider the scenario shown in Figure 1.

Two LTE systems use adjacent channel frequency bands and their cell areas are overlapped. LTE terminal stations (UEs) are assumed to be spread homogeneously in the coverage of each LTE base station (eNB). One of LTE base

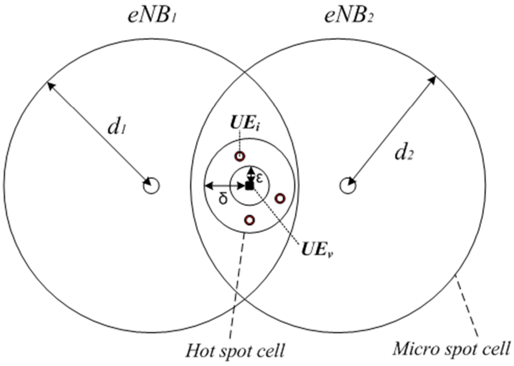

Figure 1. Geometry for the scenario

stations is a wanted transmitter (*eNB₁*) and the other is an interfering transmitter (*eNB₂*). A terminal station of a wanted transmitter is the victim station (UE_v) and terminal stations of an interfering transmitter are interfering stations (UE_{is}). The assumption is given that interfering stations (UE_{is}) are located around any victim station (UE_v) and UE_{is} cause the potential ACI to a UE_v. The distribution of the received aggregate ACI to a UE_v depends on random variable factors. Radom variable factors are the transmission power of UE_{is}, the median pathloss, shadow fading, the adjacent channel interference ratio (ACIR), and a number of UE_{is}. It is assumed that ACIR is a certain value fixed identically for all interfering stations. The distribution and the concurrent transmission number of terminal stations in the cell are random variables. These random variables are used to calculate the distribution of the aggregate ACI.

The assumption of the geometry as shown in Figure 1 is as follows. UE_v is randomly distributed in the circle of the radius d_1 of eNB_1. UE_{is} are distributed uniformly within the radius d_2 and an angular ring with both inner radius of ϵ and outer radius of δ. The inner radius of ϵ defines a minimum distance among terminal stations of UE_v and UE_{is}. The outer radius of δ is determined to become the maximum radius where the distribution area of multiple interfering stations becomes an effective interference region because the interfering reception power to a victim station is within the range of valid values. The propagation model is a composite median pathloss and shadow fading with Log-normal distribution. Shadow fading model is assumed to have the path correlation among terminal stations.

III. ANALYTIC DERIVATION OF OUTAGE PROBABILITY

Considering ACI dominant environment in the interference, the received signal to interfering power ratio (SIR) to UE_v is represented as follows.

$$\begin{aligned} SIR &= \frac{P_{eNB}\cdot PL_{eNB-UEv}}{I_{UEi}} = \frac{P_{eNB}\cdot PL_{eNB-UEv}}{\sum P_{UE_i}\cdot \partial_{UE_i}\cdot PL_{UE_i-UE_v}} \\ &= \frac{P_{eNB}\cdot C_1\cdot {d_1}^{-\gamma_1}\cdot\vartheta_1}{\sum P_{UE_i}\cdot\partial_{UE_i}\cdot C_2\cdot {d_2}^{-\gamma_2}\cdot\vartheta_2^i} = K\cdot\frac{{d_1}^{-\gamma_1}\cdot\vartheta_1}{\sum {d_2}^{-\gamma_2}\cdot\vartheta_2^i} \end{aligned} \tag{1}$$

where:

P_{eNB} is the transmit power of a wanted transmitter

$\sum P_{UE_i}$ is the transmit power of interfering stations

$PL_{eNB-UEv}$ is the composite median pathloss and shadow fading of a wanted transmitter to a victim station

$PL_{UE_i-UE_v}$ is the composite median pathloss and shadow fading of an interfering station to a victim station

∂_{UE_i} is ACIR, which means the adjacent channel interference ratio

Adjacent channel interference gives rise to extraneous power of the received signal to a victim station. The adjacent channel interference is the sum of the power both that interfering stations emit into a victim station's channel known as the unwanted emission and that interfering stations pick up from a victim station's channel known as the adjacent channel selectivity (ACS). ACS occurs and do not completely eliminate an interfering signals because radio frequency (RF) filters required a roll-off. Therefore, a victim station emits some power in the adjacent channel picked up by an interfering station. An interfering station receives some emissions from a victim station's channel due to the roll off of the selectivity filters.

C_1, d_1, and γ_1 are the parameters of the median pathloss model between a victim station and a wanted transmitter, C_2, d_2, and γ_2 are the parameters of the median pathloss model between a victim station and an interfering station. ϑ_1 and ϑ_2^i are the Log normal random variables having zero-means, variances of σ_1^2, σ_2^2 between a victim station and a wanted transmitter link and between a victim station and an interfering station, respectively. K is a constant to substitute all the constant values.

With the log-normal approximation in the denominator of (1) PDF and cumulative distribution function (CDF) of SIR can be derived. Firstly, we transform the SIR of (1) into a SIR in the decibel scale for ease of the derivation.

$$\begin{aligned} SIR\ (dB) &= 10\log_{10}\left(K\cdot\frac{{d_1}^{-\gamma_1}\cdot\vartheta_1}{\sum {d_2}^{-\gamma_2}\cdot\vartheta_2^i}\right) = 10\log_{10}\left(K\cdot\frac{\tau\cdot\aleph_1}{\aleph_I}\right) \\ &= 10\log_{10}(K) + 10\beta\left(\hat{\tau} + \widehat{\aleph_1} - \widehat{\aleph}_I\right) \end{aligned} \tag{2}$$

where, $\hat{x}$ is defined as *ln(x)* and β is 1/*ln(10)*.

With a few mathematical manipulations the PDF of $\hat{\tau}$ is obtained.

$$\text{PDF}\ (\hat{\tau}) = \begin{cases} \frac{2}{\gamma_1 D^2} e^{-\frac{2\hat{\tau}}{\gamma_1}}, & -\gamma_1 \ln(D) \le \hat{\tau} < \infty \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

Because, both $\widehat{\aleph_1}$ and $\widehat{\aleph}_I$ have a Gaussian distribution and the submission of the Gaussian random variables is a Gaussian random variable [4]. And, $\widehat{\aleph_1}$ or $\widehat{\aleph}_I$ has a Gaussian distribution:

$$f(\widehat{\aleph}) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{(\hat{\aleph}-\mu)^2}{2\sigma^2}\right) \tag{4}$$

where, $\mu = -\mu_I$ and $\sigma^2 = \sigma_1^2 + \sigma_I^2$.

The PDF of SIR in dB is obtained through the convolution of PDF ($\hat{\tau}$) and $f(\widehat{\aleph})$ as follows.

$$f_X(x) = \frac{1}{5\gamma_1\beta} e^{-2\theta x_t} Q(-x_t + \theta) \tag{5}$$

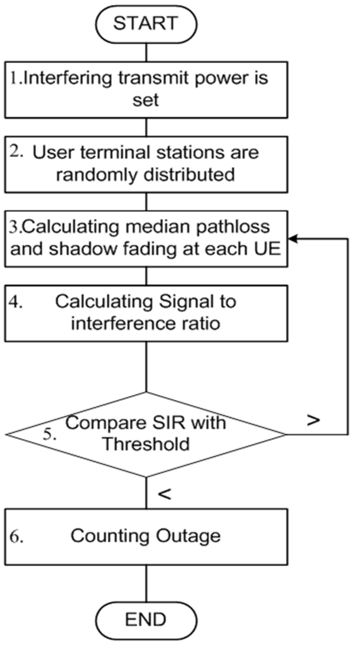

Figure 2. Monte-Carlo Simulation

where, $x_t = \frac{1}{\sigma}\left(\frac{x}{10\beta} - \ln\left(\frac{K}{D^{\gamma_1}}\right) - \mu - \frac{\sigma^2}{\gamma_1}\right)$, $\theta = \frac{\sigma}{\gamma_1}$, and $Q(y)$ is defined as $\int_y^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} dt$

CDF of SIR in dB is derived using integration by parts and results are as follows.

$$F_X(x) = \int_{-\infty}^{x} f_x(t)dt = Q(-x_t - \theta) - e^{-2\theta x_t} Q(-x_t + \theta) \quad (6)$$

where, x_t and θ are the same as those in (5)

Finally, we can have a formulation for the outage probability defining Δ, which is the threshold of the outage as follows.

$$\begin{aligned} Prob\ (SIR < \Delta) &= F_x(\Delta) \\ &= Q(-\Delta_t - \theta) - e^{-2\theta\Delta_t} Q(-\Delta_t + \theta) \quad (7) \end{aligned}$$

where, $\Delta_t = \frac{1}{\sigma}\left(\frac{\Delta}{10\beta} - \ln\left(\frac{K}{D^{\gamma_1}}\right) - \mu - \frac{\sigma^2}{\gamma_1}\right)$, $\theta = \frac{\sigma}{\gamma_1}$

IV. SIMULATION

Figure 2 shows the flow diagram of the Monte-Carlo simulation.

Step1: The emission power of UE_i is set to 23dBm.

Step2: All LTE terminal stations are randomly distributed in the cell.

Step3: The median pathloss and shadow fading between a wanted transmitter and a victim station is calculated. The median pathloss and shadow fading between an interfering station and a victim station is calculated.

Step4: The received signal to interfering power ratio (SIR) to a victim station is calculated.

Step5: SIR value is compared with reference threshold value of the predefined SIR. Reference threshold value of the received signal to interfering power ratio is defined from the quality of service of LTE terminal station. If a calculation value in Step4 is smaller than a reference threshold, the outage is happened and the outage means the blocking event. If a calculation value in Step4 is larger than a reference threshold, a call of a terminal station is not dropped, goes to Step 3.

Step6: Total outage is counted.

V. RESULTS

Let us consider the validation of the derived equation using the Monte-Carlo simulation.

We assumed the coexistence scenario of two E-UTRA (LTE) systems, which have the bandwidth of 10MHz and assign at adjacent channel bands without the guard band.

The base station of LTE system known as Evolved Node B (eNB) has the transmit power (*PeNB*) of 46dBm and the antenna gain with 12dBi including the feeder loss of -3dB. The terminal station of LTE system (UE) has the transmit power of 23dBm and the antenna gain of 0dBi. Cell radius (d) of eNB is 500m. Inner radius (ϵ) is 1m when MCL is about 30dB (including 2dB body loss). Outer radius (δ) is 19m. UEs are uniformly distributed within the cell. ACS of a UE is 33dB. For predicting the radio propagation characteristics, both extended Hata model and Motley-Keenan formula are used. The extended Hata model [1] applies for calculating to the pathloss of the desired link between a wanted transmitter (eNB) and a victim station (UE). The Motley-Keenan formula [4] applies for the interfered link between interfering stations and a victim station in the small cell environment. Long term fading known as shadow fading is Log normal random variable having zero-mean and variances. The variance of σ_1^2 is 12dB for the desired link and the variance of σ_2^2 is 4dB for the interfered link. Total pathloss value of the communication link is the sum of the median pathloss and long term fading value.

Attenuation factors and the constant of the applied median pathloss model are used as follows: attenuation exponent (α_1) 3.52 and constant (C_1) 10^{-2} in the extended Hata model and (α_2) 2.0 or 3.5and constant (C_2) $10^{-3.15}$ in the Motely-Keenan. The used pathloss equations are shown in (8) and (9).

$$PL_{eNB\text{-}UE} = C_1 \cdot d_1^{-\gamma 1} = 10^{-2} \cdot d_1^{-3.52} \quad (8)$$

$$PL_{UE\text{-}UE} = C_2 \cdot d_2^{-\gamma 2} = 10^{-3.15} \cdot d_2^{-2} \quad (9)$$

Figure 3 shows CDF of the outage probabilities on both pathloss attenuation (α_2) of 2.0 or 3.5 in the indoor interfered links and interfering station densities λ of 2 or 4. BEM OOB limit is assumed as -10dBm/10MHz. ACIR is calculated as 1/((1/ACS)+(1/ACLR)), where, ACLR means the adjacent channel leakage ratio. Normally, ACLR of LTE UE defines as 30dB+X at the first adjacent channel. In Figure 3, the analytic derivation results are in good agreement with the Monte-Carlo simulation results. Also, we can find that both larger number of interfering stations and lower pathloss exponents enhance the accuracy of derivation. This enhancement is the reason that large numbers of samples make the approximation more precise by central limit theorem, and large pathloss exponent does the deviation of the interference levels to increase according to the distance between interfering users and a victim station.

Figure 4 shows CDF of outage probabilities on both BEM levels of 0dBm or -20dBm in the indoor interfered links. Interfering station density (λ) is 2 and the pathloss attenuation (α_2) is 3.5. Outage probabilities are almost consistent on analytical as well as simulation results. In Figure 4, we can identify that as we allow more interference into adjacent band by increasing BEM OOB limit, the outage probability increases due to the increased interference. If we set a minimum SIR of 0dB for 0.1 error rate (outage probability) in the application, then, BEM OOB limit of -20dBm should be selected. Finally, the approximation equation of the derived outage probability can be used instead of the simulation results and it can also be applied for calculating BEM OOB limits that require the outage probability of a victim system.

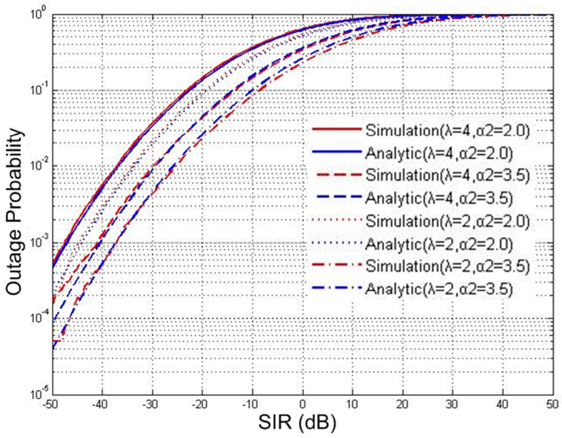

Figure 3. Outage Probabilities for pathloss exponents & an interfering user density

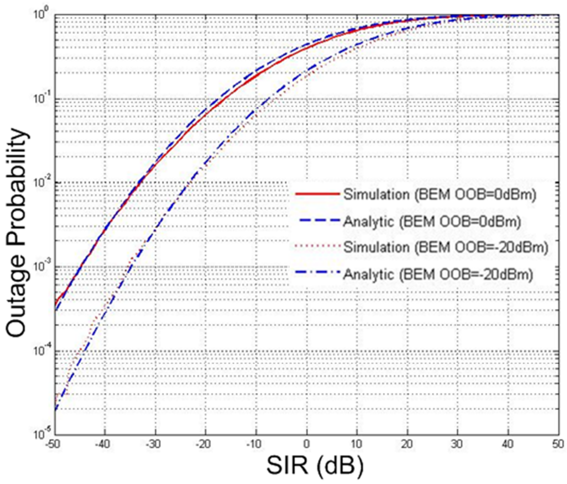

Figure 4. Outage Probabilities for BEM OOB limits

VI. CONCLUSIONS

In this paper, we derived an optimized probability formula for outages due to the unwanted emission of the interfering LTE stations in the adjacent channel bands. Analytic results of the mathematical formula were compared with statistical Monte-Carlo (MC) simulation results. For Monte-Carlo simulation, it is assumed that terminal stations are uniformly distributed around the hot spot cell area. For optimized formulation derivation, the composite median pathloss and long-term fading have log-normal approximation.

As a result, the Log-normal approximation performs well in spite of a large deviation of interference received from both near and far away terminals although there are some mismatches in absolute values, when outer radius is 19m and inner radius of 1m. Also, we can apply for calculating the out of band emission limit of block edge mask. The analytic and Monte-Carlo simulation results are useful for current and future network system performance analysis.

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