Journal of ELECTRICAL ENGINEERING, VOL 72(2021), NO2, 125–128

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COMMUNICATIONS

Estimation of the surface user distribution influence on the interference from adjacent cells in CDMA network

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In this paper we consider the network of mobile users where CDMA technique is used in cells. The dependence of disturbances/interference in the uplink direction as a result of surface user distribution in the neighbouring cells is determined. Three user distribution types are considered: the uniform one, decreasing from the cell centre to the rim and the increasing one. The interference calculation is performed using mean values of user distance from the cell centre. It is proved in the paper that interference caused by decreasingly and increasingly distributed users may differ from the interference caused by the cell with uniform user distribution by not more than $\pm 75\%$.

K e y w o r d s: CDMA mobile systems, interference, user surface distribution, attenuation coefficient, power ratio

1 Introduction

Code Division Multiple Access (CDMA) is the modern technique used, besides other goals, to increase traffic capacity of mobile network [1] - [6]. Traffic capacity is influenced by a number of factors and among them is also interference. The technique is most sensitive to the interference in the uplink direction, *ie* from the user to the base station (BS). In [1] - [6] procedures for determining the dependence of interference on various factors such as emission power control, adjacent cells, propagation coefficient are presented. Uniform users surface distribution in the cells is usually considered. However, different users' distribution in the cell may affect the emission power extent [7], [8]. It is demonstrated in this paper how users' surface distribution in the adjacent cells affects the outside disturbances *ie* interference which arises from the influence of adjacent cells to the considered cell. The analysis in this paper is related to the uplink direction meaning that interference is calculated at the receiver in BS, contrary to the analysis in [9] where analysis is performed for downlink direction and interference calculated at the place of mobile user. We provide a survey of existing solutions dealing with the interference calculation in CDMA network while the model of considered cells and the method of interference estimation and calculation.

2 Existing knowledge

Procedures to determine traffic characteristics of the network/cell based on CDMA techniques are defined long ago [1], [2], [4]. There is an essential difference between the classical queueing theory methods applied in older techniques and these methods. The number of traffic resources in older techniques was a priori known thus causing that the maximum number of simultaneous connections was also known. This limitation in CDMA techniques is not so strict *ie* traffic capacity depends on the allowed interference. The methods for determination of the most critical disturbances (uplink direction) are presented in [1] - [6] because traffic performances depend on allowed interference. Interference causes are divided into the ones originating in the same cell and the ones from the adjacent cells. Different factors (shadow fading, vocoder based on voice activity, flow-rate, bit energy) have influence on the interference and therefore on the traffic dimension. The uniform users' density distribution is supposed for the adjacent cells such that this assumption is one of the fundaments in the external interference calculation. Paper [10] presents relatively complicate method for interference calculation which considers the real users' position in the adjacent cells. The main objective of this paper is to determine the rule how users' surface distribution in the adjacent cells affects the external interference.

3 Model, assumptions and designations

Let us suppose that we have the network of mobile users based on CDMA techniques. Model of a cell is idealized such that it is shaped as a circle of the radius R. The number of active users in each cell is designated by K. It is assumed that each active user sends signal during the whole time of his activity (pauses in speech are also transmitted *ie* partial speech transmission is not considered). The same users' surface density

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https://doi.org/10.2478/jee-2021-0017, Print (till 2015) ISSN 1335-3632, On-line ISSN 1339-309X

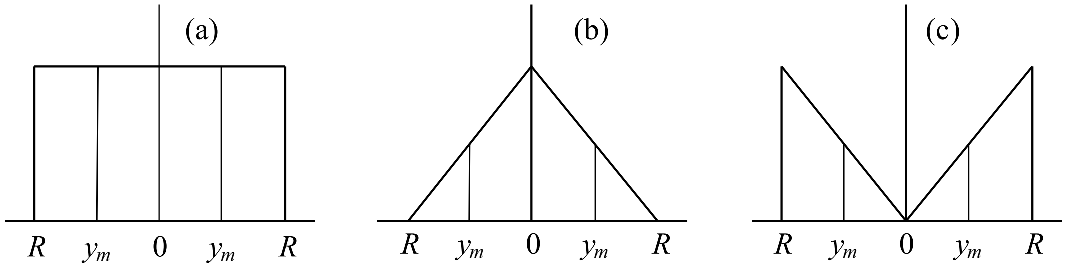

Fig. 1. Possible users' distributions in the adjacent cells: (a) – uniform, (b) – decreasing from the cell centre to the cell rim, and (c) – increasing from the cell centre

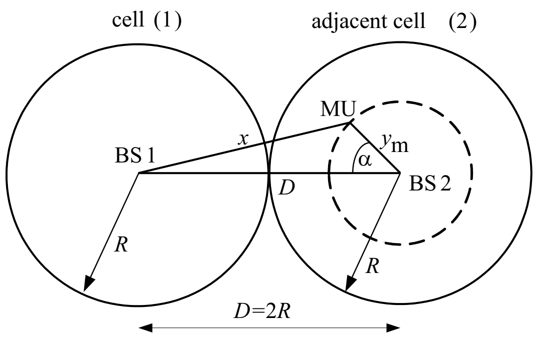

Fig. 2. Two CDMA cells model as an illustration of interference estimation: the considered cell (1) receives interference signal and the adjacent cell (2) generates interference signal

is supposed to be valid in each cell. The high-quality power control is applied in each cell such that the signals from all users at the receive side in the base station have the same power $P_{\rm r}$. It is assumed that signal power decreases with the distance d according to the exponential rule $d^{-\gamma}$ where γ is the propagation (attenuation) coefficient whose value is between 2 and 5 [7]. The users' signal power is designated by P. The maximum power of the user at the cell rim is $P_{\max}(R\gamma)$. The cumulative probability distribution, CDF, of the variable v is designated by $P\{v \leq x\} = F_v(x)$. The probability density function, PDF, is designated by $f_v(x)$.

The influence of users' distribution from the adjacent cell (2) on the interference in the considered cell (1) will be estimated in three cases, Fig. 1:

- uniform as considered in [1] - [6], Fig. 1(a),
- decreasing from the centre to the cell rim, which may be often found in reality, Fig. 1(b), [7], [8], and
- increasing towards the cell rim which means that users' surface density is minimum in the cell centre, Fig. 1(c), [7], [8].

The cases (b) and (c) are the extreme ones of those presented in [8].

The model which is used to estimate the interference of the user MU from the adjacent cell in the mobile users' network which is based on CDMA techniques is presented in the Figure 2.

4 Interference estimation

The estimation of the interference signal in the cell (1) from the adjacent cell (2) is performed in several steps:

Step 1: The mean distance of the user MU in the cell (2) from the centre of the cell, *ie* from BS2, y_m, is calculated based on the users' density distribution in the cell (2), Figure 2. This calculation may be performed by the equations (7), (9), (10) from [7]. The equations are used to determine cumulative distribution function, CDF, of the distance between the user and the cell centre at a priori defined users' distribution in the cell, $F_y(x)$.

Step 2: The probability density function, PDF, of the active users distance in the cell (2), $f_y(x)$, may be determined based on $F_y(x)$.

Step 3: The mean value of active user (MU) distance in the cell (2), y_m, is calculated starting from PDF, Fig. 1 and Fig. 2. It will be supposed that active user is on the distance ym from the cell (2) centre, BS2, when interference is estimated. It should be noted that certain mean users' distance is valid only for the assumed users' density distribution in the cell.

Step 4: The distance of the typical (mean) user MU in the cell (2) from the base station BS1, x in Figure 2, is random function of random value of the angle α, Figure 2. As typical user MU from the cell (2) may be in any point on the circle with the radius y_m in the cell (2), random angle α has uniform distribution. The mean distance x_m between the interference source MU from the cell (2) and BS1 may be calculated starting from the random function

$$x = \sqrt{D^2 + {y_m}^2 - 2Dy_m \cos\alpha}\,, \tag{1}$$

and theorem (5.29) from [11] about the calculation of the random function mean value.

Step 5: The emission power of active users in the cell (2), who are on the mean distance y_m from BS2, is designated by P_y. The value of this power depends on the users' density distribution in the cell (2) and signal attenuation γ. This power at the receiver in BS2 decreases to the level P_r and to the interference level P_i at the receiver in BS1. It is obvious that P_i depends on P_y, and mean users' distance x_m.

Step 6: It remains only to calculate the power P_i, Fig. 3.

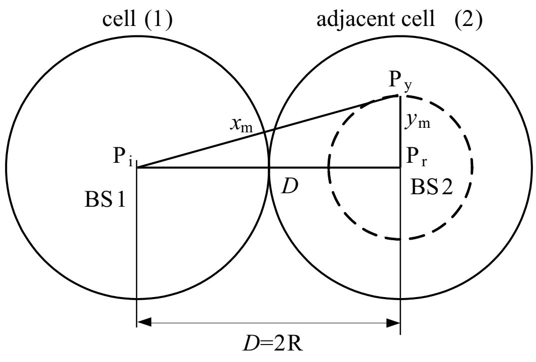

Fig. 3. Graphical illustration of the interference signal power calculation in the cell (1) as a consequence of the adjacent cell (2) influence

It is obvious from Figure 3 that the following equations are valid

$$\frac{P_i}{P_r} = \frac{P_y(x_m)^{-\gamma}}{P_y(y_m)^{-\gamma}} = \left(\frac{y_m}{x_m}\right)^{\gamma} . \tag{2}$$

Therefore, the power ratio interference signal/useful signal may be simply calculated for different users' density distributions in the cell.

5 Influence of users' density - numerical example

The values of mean distance y_m between the user in the cell (2) and BS2 for different user distributions are calculated based on the procedure explained in steps 1-3 in the Section 4 and presented in the Tab. 1.

Table 1. The mean distance y_m between the user in the cell (2) and BS2 for various distributions

	uniform Fig. 1(a)	decreasing Fig. 1(b)	increasing Fig. 1(c)
$y_m =$	$2R/3$	$R/2$	3R/4

The mean distance, x_m, between the user MU from the cell (2), who is the source of interference in the cell (1) and BS1 is now calculated using the equation (1). The calculated values for different users' distribution are presented in the Tab. 2.

Table 2. The mean distance x_m between the user MU from the cell (2) causing interference and BS1

	uniform Fig. 1(a)	decreasing Fig. 1(b)	increasing Fig. 1(c)
$x_m =$	$2.0555R$	$2.0311R$	$2.0716R$

The power ratio interference signal/useful signal, P_i/P_r, for different users' density distributions and attenuation coefficients γ is determined in the next step from the equation (2). The obtained values are presented in the Tab. 3.

Table 3. The power ratio interference signal/useful signal, P_i/P_r, for various distributions and attenuation coefficients

γ	P_i/P_r uniform Fig. 1(a)	decreasing Fig. 1(b)	increasing Fig. 1(c)
2	0.10520	0.0605	0.1311
3	0.03412	0.0149	0.0474
4	0.01106	0.0036	0.0172
5	0.00358	0.0009	0.0062

Finally, the influence of users' density in CDMA cell on the interference in the adjacent cell may be seen from Fig. 4. The ratio of the interference signal from the cell of decreasing, $P_{\rm idec}$, and increasing, $P_{\rm iinc}$, density distribution to the interference signal from the cell with uniform, $P_{\rm iu}$, density distribution (which is usually considered as the model for interference calculation) is presented in Fig. 4. It is obvious that the adjacent cell with the decreasing users' density distribution causes less interference in the considered cell, and that the adjacent cell with increasing users' density distribution increases interference in the considered cell. Such a calculation is related to all K active users in the cell.

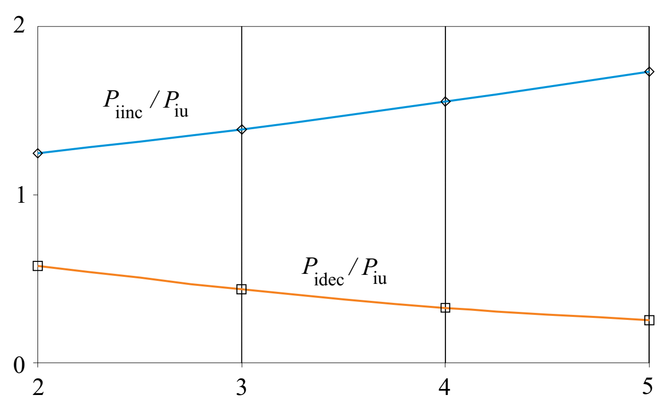

Fig. 4. The power ratio interference signal from the adjacent cell (a) – with increasing users' density $P_{\rm iinc}$ and (b) – with decreasing users' density $P_{\rm idec}$ to the power of interference signal with uniform users' density $P_{\rm iu}$

6 Conclusion

The influence of surface users' density distribution to interference from outside in the cells which use CDMA techniques and high-quality emission power control is presented in this paper. Taking uniform users' density distribution in the cells as a comparison, it is proved that interference from the cells with decreasing users' density distribution is lower than the interference from the cells with uniform distribution. And opposite, interference from the cells with the increasing users' density from BS towards the cell rim is higher than the one caused by the cell with uniform distribution.

The other conclusion is that the influence of density distribution different than uniform increases when the value of attenuation coefficient increases. As the extreme cases are considered for the decreasing and increasing distribution, it may be concluded that interference deviation in relation to the interference from the cell with uniform distribution would not be greater than $\pm 75\%$ for the attenuation coefficient $\gamma = 5$.

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Received 4 March 2021

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