THE DYNAMICS OF THE INTERFERENCE SITUATION IN THE DOWNLINK DIRECTION OF THE MOBILE COMMUNICATION NETWORK WITH CDMA TECHNOLOGY

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ДИНАМІКА ЗАВАДОВОЇ ОБСТАНОВКИ У НИЗХІДНОМУ НАПРЯМКУ МЕРЕЖІ МОБІЛЬНОГО ЗВ'ЯЗКУ З ТЕХНОЛОГІЄЮ CDMA

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Abstract. *The work is devoted to the investigation of inter-cell interference in the radio access network, provided that subscribers are moving in cells along the route indicated earlier. Very often, the trajectory of the movement of mobile stations coincides with the grid of city streets, where subscribers are moving in public transport. For a network where the cluster dimension is K = 1, the proposed methodology for studying changes in the level of intra-system interference at the input of the receiver of a mobile station when a subscriber is moving along the given path. The features of the situation where the control mode of the transmitter power of the base station is used in each cell, which provides a constant power level of the input signal when the subscriber is moving within the cell, are analyzed. The level of inter-cell interference is estimated as one of the factors on which the quality of services depends, namely, the signal-to-interference ratio at the input of the receiver of the mobile station. For specific trajectories of the movement of subscribers in neighboring cells, a law of changing the transmitter power of the base station was found, which interferes with the receiver of the mobile station in the neighboring cell. Estimated ratios are obtained for determining the level of interference when subscribers in neighboring cells are moving along parallel streets. This assessment of the dependence of the signal / interference ratio at the input of the subscriber's receiver on the speed and direction of its movement. This dependence shows that serious problems with the quality of service provided by the operator will not arise. Such an investigation allows modeling the cellular network in order to optimize the work on improving the services provided to mobile subscribers.*

Keywords: *cellular networks, mobile station, base station, predetermined trajectory of movement, intra-system interference, active subscriber, signal-to-interference ratio, quality of service, downlink.*

Анотація. *Робота присвячена дослідженню міжстільникових завад у мережі радіодоступу при умові, що абоненти рухаються у стільниках за маршрутом, що було вказано раніше. Дуже часто траєкторія руху мобільних станцій збігається з сіткою міських вулиць, де абоненти переміщуються у міському транспорті. Для мережі, де розмірність кластера K = 1, запропонована методика дослідження зміни рівня внутрісистемної завади на вході приймача мобільної станції при русі абонента по заданій траєкторії. В роботі розглядається перше коло джерел внутрішньосистемних завад. Проаналізовано особливості ситуації, коли у кожному стільнику використовується режим регулювання потужності передавача базової станції, який забезпечує постійний рівень потужності вхідного сигналу при русі абонента у межах стільника.*

Оцінюється рівень міжстільникових завад, як один з факторів, від яких залежить якість послуг, а саме відношення сигнал/завада на вході приймача мобільної станції. Для конкретних траєкторій руху абонентів в сусідніх стільниках було знайдено закон зміни потужності передавача базової станції, що створює завади приймачеві мобільної станції у сусідньому стільнику. Отримано розрахункові співвідношення для визначення рівня завад, коли абоненти у сусідніх стільниках рухаються паралельними вулицями. Дана оцінка залежності відношення сигнал / завада на вході приймача абонента від швидкості і напряму його руху. Така залежність показує, що серйозні проблеми з якісним наданням послуг, заявлених оператором, не будуть виникати. Таке дослідження дозволяє робити моделювання стільникової мережі з метою оптимізації роботи на покращення послуг, що надаються абонентам рухомого зв'язку. Наведені кількісні приклади отримані в середовищі MATLAB підтверджують теоретичні викладки.

Ключові слова: *стільникові мережі, мобільна станція, базова станція, задана траєкторія руху, внутрішньосистемні завади, активний абонент, відношення сигнал/завада, якість послуг, низхідна лінія зв'язку.*

INTRODUCTION

To increase the efficiency of using frequency resources in communication systems with mobile objects, the entire service area is divided into hexagonal cells of radius R, resulting in a flat regular hexagonal grid.

The resulting network is further divided into clusters, i.e. repeating groups of cells that form a periodic structure. Each cluster contains K cells.

The set of frequencies allocated for this cellular network is evenly distributed among the cells of the cluster. In all clusters of the network, the same frequencies and the order of their assignment to the cells are repeated. Consequently, the receiving and transmitting equipment of each base station (BS) of the cluster operates at the frequencies assigned to it.

Thus, the increase in efficiency is due to the repeated use of the same frequencies in the area of mobile radio network deployment. It should be noted that such a mode of operation of the transceiver equipment leads to unavoidable intra-system inter-cell interference, the level of which decreases with increasing cluster dimension K [1].

The first development of 1G and 2G mobile systems had low noise immunity and could provide the specified quality of service only at $K = 12$ or $K = 7$.

The latest generation of cellular 4G and 5G systems widely use technology CDMA (Code Division Multiple Access) [2]. To separate user signals and expand the spectrum, a certain system of orthogonal functions is used. In the cdmaOne, UMTS and cdma2000 technologies, the Walsh functions are orthogonal signals [3].

Due to the high noise immunity of digital broadband of CDMA technology, the dimension of the cluster can be reduced to increase the efficiency of frequency resource utilization without reducing the quality of service. It turned out that it is possible to work even with $K = 1$, when the cluster consists of one cell [4]. In this case, the efficiency is maximum, but the amount of intra-system interference also reaches the maximum value.

The purpose of this work is to propose a research methodology for assessing the dynamics of the jamming environment when subscribers are moving in cells with a certain speed and in given directions.

FORMULATION OF THE PROBLEM

Consider a fragment of the cellular network presented in Fig. 1. The central cell with base station BS_0 is surrounded by six neighboring cells with base stations $BS_i, i = 1,\ldots,6$. Since the cluster dimension is assumed to be $K = 1$, the transmitters on all BS_i use the same frequency. Synchronous operation in each cell eliminates the possibility of intra-cell interference. However, the transmitter of each BS, serving subscribers in its "own" cell, interferes with mobile stations in all neighboring cells.

For example, interference from BS from all neighboring cells arrives at the receiver input of a mobile station in the central cell MS_0. The distances from the sources of interference to the MS_0 receiver are indicated in Figure 1 through $d_i \left(x_{Bi}, y_{Bi} \right), \ i = 1,...,6$. When MS_0 is moving in its cell, the level of each interference continuously changes. There is a rather complicated noise situation, which is difficult to be mathematically analyzed.

For definiteness, we will consider only two cells: the central and neighboring No. 4. Suppose there is only one user in each cell. The first is served by BS_0, and the second by BS_4. At the same time, the transmitter of BS_4 interferes with the receiver of MS_0.

In addition, let's make a number of assumptions. Let MS_0 move in a straight line (street) from point B to point D. In the neighboring cell, MS_4 follows the line CH.

The directions of movement and speed of subscribers coincide. At the initial moment of time, MS0 and MS4 are located at points *B* and *C*, respectively (see Fig. 1). Moreover, let us assume that the power control of the base station transmitters has been adopted in the cellular network.

Figure 1 – Fragment of a cellular mobile radio network

The intercom channels BS0 and MS0 exchange messages, as a result of which the transmitter power is chosen such that a signal equal to receiver sensitivity $P_S = -137$ dBW is always received at the input MS0 [4].

The same adjustment is adopted in the neighboring cell No. 4. Thus, the input signals in the receivers of MS0 and MS4 are constant and equal to P_S [5].

Our task is to show how it is possible to find the law of change of interference from BS4 at the receiver input in the central cell as MS0 and MS4 move along parallel streets.

ANALYSIS OF CHANGES IN SIGNAL/INTERFERENCE RATIO IN DIRECT DIRECTION

We define the basic spatial characteristics of a moving object in the central cell. The current coordinates of MS0 are determined as follows. Knowing the coordinates of points *B* $(0, R)$ and *D* $\left(-R\sqrt{3}/2, -R/2\right)$, where *R* is cell radius, you can write the equation of *BD* line:

$$y = \sqrt{3}x + R. \tag{1}$$

Obviously, the length of *BD* segment equals $R\sqrt{3}$. Suppose that $R = 3$ km, and the speed of the subscriber $\upsilon = 39$ km per hour. Then the mobile subscriber covers this distance in 0.133 hours or 8 minutes. Further, when the subscriber moves, the distance from point *D* to MS0 varies according to the law

$$d_{(\text{km})} = R\sqrt{3} - \upsilon t/60, \ 0 \le t \le 8 \text{ min.} \tag{2}$$

On the other hand, the distance d can be expressed through the coordinates $MS_0\left(x_{m0}, y_{m0}\right)$ [6]:

$$d = d\left(D, MS_0\right) = \sqrt{\left(x_D - x_{m0}\right)^2 + \left(y_D - y_{m0}\right)^2}.$$

In view of (1) we get:

$$d = \sqrt{\left(-R\sqrt{3}/2 - x_{m0}\right)^2 + \left(-R/2 - x_{m0}\sqrt{3} - R\right)^2}.$$

Finally, you can write

$$4x_{m0}^2 + 4R\sqrt{3}x_{m0} + 3R^2 - d^2 = 0. \tag{3}$$

Solving equation (3), we obtain the desired coordinates:

$$x_{m0} = -\frac{R\sqrt{3}}{2} + \frac{d}{2} \tag{4}$$

and

$$x_{m0} = \sqrt{3}x_{m0} + R = -\frac{R}{2} + \frac{\sqrt{3}d}{2}. \tag{5}$$

Now it is possible to determine distance $d_4\left(x_{B4}, y_{B4}\right)$ to the source of interference. In fact, if the coordinates of base station BS4 are $\left(R\sqrt{3}, 0\right)$, and MS0 coordinates are determined by expressions (4) and (5), then we can write

$$d_4\left(x_{B4}, y_{B4}\right) = \sqrt{\left(x_{B4} - x_{m0}\right)^2 - \left(y_{B4} - y_{m0}\right)^2} = \sqrt{d^2 + R^2}, \tag{6}$$

where d determined by expression (2). Justice (6) is easily verified. Indeed, when $t = 0$ station MS0 is at point B. Then $d = R\sqrt{3}$ and $d_4\left(x_{B4}, y_{B4}\right) = 2R$. When $t = 8$ min MS0 is at point D, where $d = 0$ and $d_4\left(x_{B4}, y_{B4}\right) = R$ (see Fig. 1).

Now consider the adjacent cell No. 4. To maintain a constant signal level at the input of the subscriber receiver, the transmitter power of the base station P_{trB4} should change depending on the position of the MS4 on the CH line. Given the coordinates of points $C\left(-R\sqrt{3}/2, R/2\right)$ and $H\left(-R\sqrt{3}, -R\right)$, we write the equation of CH line:

$$y = \sqrt{3}x + 2R. \tag{7}$$

By analogy with the MS0, let's find the current coordinates of the MS4 when the subscriber is moving from point C to point H. The distance d from point H to MS4 can be determined by the formula (2) or based on the equation

$$d = d_4\left(H, MC_4\right) = \sqrt{\left(x_H - x_{m4}\right)^2 + \left(y_H - y_{m4}\right)^2}.$$

After transformations we get

$$4x_{m4}^2 + 8\sqrt{3}R x_{m4} + 12R^2 - d^2 = 0. \tag{8}$$

Solving equation (8), we get the first coordinate of MS4:

$$x_{m4} = -R\sqrt{3} + \frac{d}{2}.$$
(9)

We find the second coordinate from (7):

$$y_{m4} = \sqrt{3}x_{m4} + 2R = -R + \frac{\sqrt{3}}{2}d.$$
(10)

We determine the distance from BS$_4$ to MS$_4$:

$$r_4 = \sqrt{\left(x_{B4} - x_{m4}\right)^2 + \left(y_{B4} - y_{m4}\right)^2} = \sqrt{d^2 - dR\sqrt{3} + R^2}.$$
(11)

To calculate the signal power and interference at the subscriber receiver input, it is necessary to choose a radio propagation model.

In urban conditions, direct visibility between antennas of BS and MS is usually absent, and the reflected rays entering the receiving antenna are independent, and their intensity obeys a random law.

In such conditions, it is advisable to use the Okumura-Hata empirical model [1, 2, 7], which allows you to calculate the median value of the input signal, i.e. the value that can be exceeded in 50% of cases.

Based on this empirical formula [4], we determine how the BS$_4$ transmitter power should change so that when MS$_4$ is moving along the *CH* line, the useful signal power at the receiver input remains constant and equal to P_S:

$$P_{\mathrm{trB4}} = P_{S(\mathrm{dBW})} - G_{BS_{(\mathrm{dB})}} + 69.55 + 26.16 \lg f_{(\mathrm{MHz})} -$$
$$-13{,}82 \lg h_{B(\mathrm{m})} + \left[45 - 6{,}55 \lg h_{B(\mathrm{m})}\right] \lg r_{4(\mathrm{km})}, \text{ dBW.}$$
(12)

Let's substitute in (12) the typical for the mobile network parameter values, i.e. $P_S = -137$ dBW, $G_{BS} = 12$ dB, $f = 880$ MHz and $h_B = 70$ m. The value r_4 is calculated by (11) taking into account (2).

In MATLAB environment, it is possible to calculate and plot P_{trB4} time dependence (Fig. 2).
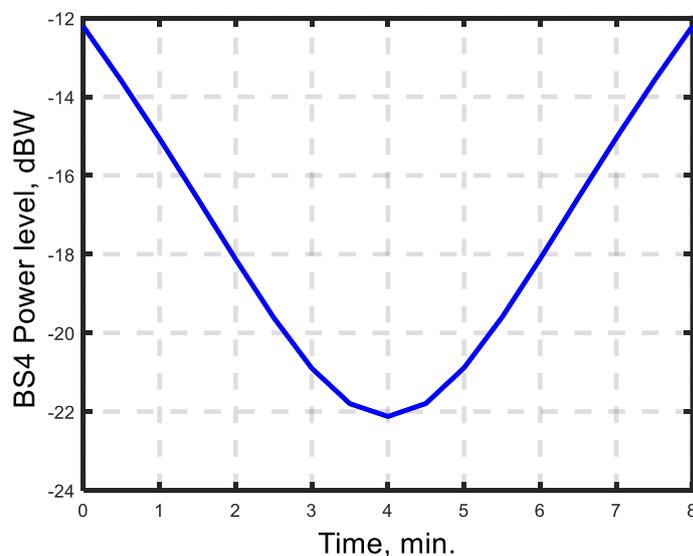

Figure 2 – Current value of transmitter power BS$_4$

As you can see, when MS$_4$ is moving along the *CH* line, the change in transmitter of BS$_4$ power reaches 10 dB.

By transmitting a useful signal to a mobile subscriber in its cell, the BS$_4$ transmitter simultaneously creates intra-system interference to the mobile subscriber in the central cell.

Note that with simultaneous movement of subscribers of MS$_4$ and MS$_0$ P_{trB4} will change as well as distance $d_4\left(x_{B4}, y_{B4}\right)$ (see Fig. 1 and Fig.2).

According to the Okumura–Hata formula [1, 2] we find the interference power at the input of the subscriber receiver of MS$_0$:

$$P_{\text{int}} = P_{\text{trB4(dBW)}} + G_{\text{BS(dBW)}} - 69.55 - 26.16 \lg f_{(\text{MHz})} +$$
$$+13.82 \lg h_{B(\text{m})} + \left[45 - 6.55 \lg h_{B(\text{m})}\right] \lg d_{4(\text{km})}, \text{ dBW.} \tag{13}$$

Substituting in (13) the expression (12), we obtain:

$$P_{\text{int}} = P_S + \left[45 - 6.55 \lg h_B\right]\left(\lg r_4 - \lg d_4\right), \text{ dBW.} \tag{14}$$

For the signal-to-noise ratio at the input of the MS$_0$ receiver, the equality is true

$$\rho_0^2 = P_S - P_{\text{int}} = \left[45 - 6.55 \lg h_B\right] \lg\left(d_4/r_4\right), \text{ dB.} \tag{15}$$

Expression (15) completes the study of the jamming situation in the cellular network.

In the MATLAB environment, we compile a calculation program for constructing a graph, which is shown in Fig. 3.
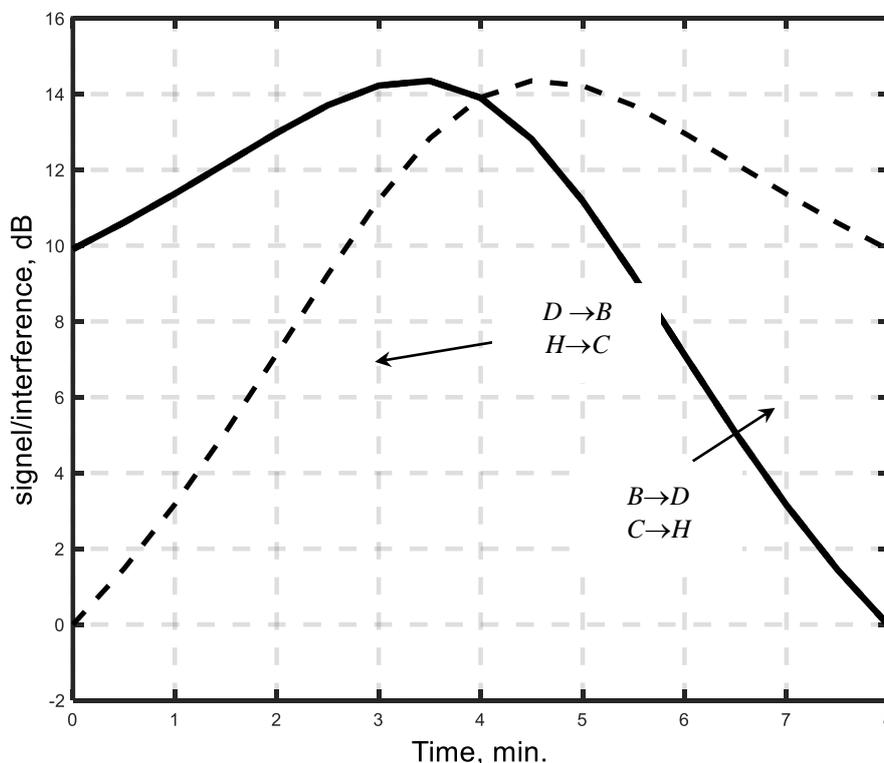

Figure 3 – The current value of the signal/interference ratio at the receiver input of MS$_0$

The first curve (solid line) gives an idea of the nature of the intra-system interference change at the input of the MS$_0$ receiver in the central cell from the BS$_4$ transmitter in the neighboring cell for eight minutes, during which the subscriber moves from point B to point D.

It should be noted that at the point D, the power of the useful P_S signal is equal to the interference power P_{int} (see Fig. 1). In fact, here $r_4 = d_4$, therefore, according to (14), we have $P_S = P_{int}$ and by the formula (15) we find $\rho_0^2 = 0$ dB.

The second curve (dashed line) corresponds to the case when both stations (MS_0 and MS_4) move in the opposite direction and travel all the way in the same eight minutes. In the middle of the path, the graphs intersect, showing even symmetry of the curves.

As you can see, the magnitude of the change in the ratio ρ_0^2 can reach 14 dB.

CONCLUSIONS

The methodology for investigation the interference situation in the cellular network of mobile radio communications and a specific example to demonstrate its capabilities are presented.

Taken into account not only the technical parameters of the receiving and transmitting equipment, but also such performance characteristics as the direction and speed of movement of subscribers.

It is established that the magnitude of mutual interference is closely related to the position of the subscriber in the neighboring cell, which, in turn, affects the power level of the BS_4 transmitter creating interference, as shown in Fig. 2.

Further development of this technique will allow solving more complex problems, opening up new opportunities for mathematical modeling and optimization of the parameters of cellular radio networks.

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