RADIOSIGNALS DYNAMIC RANGE IN SPACE-SCATTERED MOBILE RADIOCOMMUNICATION NETWORKS

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The aim of the present paper is to outline and illustrate possible ways to practically implement the technique for tentative prediction of signals ensemble dynamic range at the receiver input in cellular networks. To illustrate the practicability of this technique the results of its utilization for prediction of reception conditions in FDMA, TDMA and CDMA networks are presented as well as the results of its comparison to the technique based on theoretical probabilistic evaluation of sample range of signal levels at the reception point.

INTRODUCTION

Intensive development of radiocommunication systems made modern urban radio environment substantially more complex. Rational frequency planning of this systems as well as shrinking of cell sizes along with the base station transmitter power decrease to several watts/channel or less makes it possible to substantially lower the probability of mutual interference on the main, adjacent and spurious receive channels. Under these conditions, however, we have to reckon with the probability that there are comparatively strong signals from the nearest mobile stations present at the mobile or base station:

♦ signals whose frequencies does not coincide with the receiving frequency but can cause communication quality deterioration due to nonlinear effects in the receiver: intermodulation, blocking, cross modulation and local oscillator voltage noise conversion;

♦ signals whose frequencies coincide with the receiving frequency of the weak signal from a distant mobile station (for example, if CDMA or TDMA radio interface standards are employed), which may cause the radio signal amplification/conversion path to be overloaded and thus introduce the requirement for provision of a wide power adjustment range (where this procedure exists at the system level) when communication with the nearest mobile stations is taking place.

This paper is aimed at development of a viable technique for probability evaluation of strong input signals under conditions of reception in space-scattered radiocommunication networks, particularly high-capacity cellular or trunking networks.

INITIAL MODELS AND DEFINITIONS

1. As the radio environment parameter which characterizes the strong signals at the receiver input we use the value of the dynamic range $\boldsymbol{D}$ of the ensemble $\boldsymbol{N}$ of input signals:

$$D_P = \frac{P_{max}}{P_0} = \frac{\Pi_{max}}{\Pi_{min}} = \left(\frac{E_{max}}{E_{min}}\right)^2 = D_E^2, \qquad (1)$$

$$D = 10\, lg\, D_P = 20\, lg\, D_E .$$

This expression contains the following terms:

♦ power characteristics of the predominant input signal - the power flux density Π_{max} and the field strength E_{max} of the predominant field at the point of receiving antenna location; the power P_{max} of this signal at the receiving antenna output;

♦ the values Π_{min}, E_{min} of the receiver sensitivity limit "over the field" and the receiver antenna input sensitivity value P_0 of the in power measurement units.

2. As the radiowave propagation model we use the well-known hyperbolical approximation of the electromagnetic field power flux density Π on the distance $\boldsymbol{R}$ to its emitter:

$$\Pi = C_\nu P_{etr} / R^\nu, \; P_{etr} = G_a P_{tr}, \; C_\nu = const, \qquad (2)$$

where P_{etr} - the equivalent isotropic radiated power (EIRP), P_{tr} - the power fed to the emitter antenna; G_a - the antenna gain, C_ν - the constant (ν=2 for free space propagation, ν=4 may be used in some cases (for radiowave propagation with interference of direct and reflected rays in the far zone for the VHF range and the lower part of the UHF as well as in cases when propagation path shadowing by urban buildings, structures and foliage is initially taken into account [1,2], ν=2÷12 when the "regressive" in-building propagation model [3,4] for the UHF range is used).

3. As the receiver parameter which characterizes the receiver susceptibility to influence of strong signals outside the receiver (operating) bandwidth we use the value of the interference effects free input dynamic range of receiver [5]:

$$D_{in} = P_{max}/P_0 \in \{D_{im}, D_{ds}, D_{cm}, D_{onm}, D_{inm}, D_b\}, \qquad (3)$$

where P_0 is the lower signal power limit of a receiver antenna input sensitivity; P_{max} may be defined using, particularly, the intermodulation criterium for determining the intermodulation free dynamic range D_{im} of the receiver, the desensitization criterium for determining the desensitization free dynamic range D_{ds} of the receiver, the cross modulation criterium for determining the cross modulation free dynamic range D_{cm} of the receiver, and the respective criteria for determining the local oscillator noise mixering free dynamic range D_{onm}, the intermediate frequency paths interference free dynamic range D_{inm}, or the border frequency paths interference free dynamic range D_b of the receiver.

4. The area of the radius $R_{max}=(C_\nu P_{etr}/\Pi_{min})^{1/\nu}$ around the location point of the victim receiver with the sensitivity limit Π_{min} shall be considered as the spatial area of potential interfering interaction of radiotransmitters. Spatial arrangement of emitters within this area shall be characterized by the average spatial emitter density function of coordinates: the function $\rho(\alpha,\theta,R)$ in spherical coordinates for three-dimensional emitters arrangement or $\rho(\alpha,R)$ in polar coordinates for two-dimensional emitters arrangement; here α,θ are the azimuth and elevation angles of the signal arrival direction; R is the distance from the center of the area. We shall consider the functions $\rho(\alpha,R)$ and $\rho(\alpha,\theta,R)$ as slowly varying functions; thus the spatial density of emitters in the vicinity of the receiver location point which corresponds to the zero of coordinate system may be assumed as constant. In the general case, we shall assume $\rho=const$ for the m-dimensional vicinity of the receiver.

5. As the model of probabilistic character of spatial distribution of emitters in the vicinity of he radio receiver we shall use the known Poisson model of random distribution of points in space:

$$p_k(N_{\Delta V}) = \frac{N_{\Delta V}^k}{k!} exp(-N_{\Delta V}), \qquad (4)$$

where $p_k(N_{\Delta V})$ is the probability that exactly k point emitters will fall into a certain element of space ΔV if the average number of emitters within this element is equal to $N_{\Delta V}$.

6. At the initial stage of analysis we shall assume that all emitters are isotropic and have equal EIRP ($C_\nu P_{etr}=const.$) and that the receiver antenna is omnidirectional and its equivalent area is S_e ($P_0=S_e\Pi_{min}=const$).

7. We shall neglect the dependence of characteristics of the emitter antennas, receiver antenna and propagation model (2) characteristics on frequency assuming that the transmitting frequency range of emitters is limited.

For these conditions, the predominant signal with the power $P_{max}=S_e\Pi_{max}$ at the receiver input belongs to the nearest emitter whose potential influence on the victim receiver has not been compensated by regulatory or technical measures. Since distances from the victim receiver to interferers are random, the magnitude P_{max} and the dynamic range D_P of oscillations in the ensemble of input signals are functionally related random values and can be characterized by the corresponding probability distributions. The type of these distributions is determined by models (2),(4).

PROBABILITY DISTRIBUTION OF SIGNALS DYNAMIC RANGE AT THE RECEIVER INPUT

For m-dimensional spatial distribution of emitters, the distance R_{min} to the nearest emitter may be defined as the maximum radius of the spherical receiver vicinity ΔU free from emitters. Taking account of possible regulatory and technical ways to

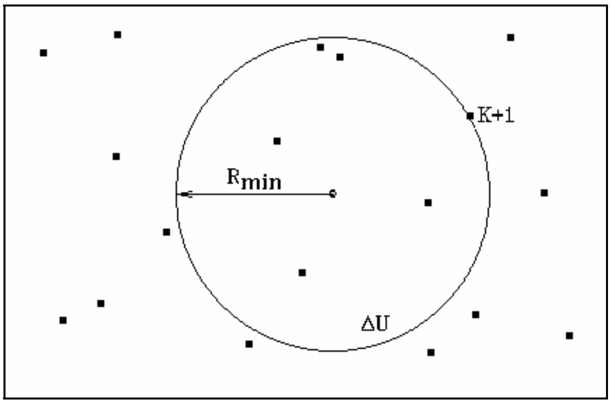

Fig. 1

provide electromagnetic compatibility of neighboring radio stations (compensation, blanking, spatial EMI shielding, coordination of transmit times), which allow one to rule out the influence of signals from a certain number K of the nearest emitters (see Fig.1), the radius of this vicinity will be equal to the distance from the receiver to the $K+1$-th distant emitter. This emitter may be considered as the nearest interferer. Therefore the probability distribution density for the distance R_{min} to the nearest interferer is [6]:

$$w(R_{min}) = \frac{G^H m}{\Gamma(H)} R_{min}^{Hm-1} exp(-GR_{min}^m); \qquad (5)$$

$$G = \rho a_m > 0, \quad H = K+1 > 0, \quad m > 0, \quad R_{min} \geq 0;$$

$\Gamma(*)$ -gamma function. $GR_{min}^m = N_a(R_{min})$ represents the average number of emitters within the m-dimensional spherical vicinity ΔU with the radius R_{min} around the receiver location point. Using the apparent functional relationship between the dynamic range D_P and the minimum distance R_{min}

$$D_P = \frac{c_\nu P_{etr}}{\Pi_{min} R_{min}^m},$$

we obtain from (5) the law for probability distribution of the signals dynamic range at the receiver input; the distribution is determined by the level of the signal from the H-th distant emitter and this law has the form of the exponential-hyperbolic distribution [6]:

$$w(D_P) = \frac{N_a^H m}{\nu\Gamma(H)} D_P^{-(Hm+\nu)/\nu} exp(-N_a D_P^{-m/\nu}); \qquad (6)$$

$$D_P \geq 0, N_a \geq 0, \nu > 0; m > 0.$$

In this distribution, N_a represents the average number of emitters within the spherical area of potential interfering field interaction with the radius $R_{max}=(C_\nu P_{etr}/\Pi_{min})^{1/\nu}$ limited by the receiver sensitivity on the main receive channel in case the average spatial density of emitters within this whole area is constant and equal to the average density ρ of the random spatial distribution of emitters in the vicinity of the receiver:

$$N_a = GR_{max}^m = \rho\pi^{m/2} R_{max}^m \big/ \Gamma(1+m/2) \geq 0 . \quad (7)$$

The expression for the distribution (6) moments is:

$$m_n(D_P) = N_a^{n\nu/m} \frac{\Gamma(H - n\nu/m)}{\Gamma(H)}, \; H - n\nu/m > 0 . \quad (8)$$

The expressions (6),(8) thoroughly characterize probabilistic properties of the dynamic range of emissions (signals) at the receiver location point in the simplest case when EIRPs of emitters that are randomly located within the potential interfering interaction area are constant in time and equal in the direction to the radio receiver. In these expressions, $D_P \geq 0$, although the domain $D_P > 1$. The condition $D_P < 1$ means that if the Poisson model of spatial emitters location (4) is used then the probability that these emitters are absent within the area around the receiver with the radius R_{max} is not equal to zero for any finite ρ, R_{max} although this probability is generally extremely low.

It is necessary to point out that $n\nu/m \geq H$ and the distribution (6) have no initial moments in the most practically important cases. Nevertheless the obtained expressions make it possible to predict the dynamic range of signals during radio reception in space-scattered radio equipment groups on the basis of the evaluation of the upper boundary of the confidence interval $[0, D_{P0}]$ which includes the evaluated value of D_P with the probability p:

$$D_{P0} = arg\{P(D_{P0}) = p\} , \quad (9)$$

$$P(D_{P0}) = \Gamma(H, N_a D_{P0}^{-m/\nu}) \big/ \Gamma(H) ;$$

$\Gamma(H, N_a D_P^{-m/\nu})$ is the incomplete gamma function of the second kind.

For example, if in the considered situation the receiver antenna input dynamic range D_{in} is known then the probability $p(D_P > D_{in})$ that it will be exceeded by the dynamic range of input signals is determined by the simple relationship:

$$p(D_P > D_{in}) = 1 - \Gamma(H, N_a D_{in}^{-m/\nu}) \big/ \Gamma(H) . \quad (10)$$

The distribution (6) is obtained using model (2) and the dynamic range of signals is determined using the power flux density (or power of individual signals at the receiver antenna input). If we use the propagation model of the type (2) based on the field intensity, in which the exponent is two times less than ν , then the form of expressions (6),(8) and the meaning of their parameters will not change, but the condition for existence of moments in this distribution will be improved.

The arguments given below allow one to substantially improve limitations on applicability of models and relationships derived above; these limitations were assumed for derivation of the distribution (6).

Signals dynamic range estimation for FDMA mobile stations

Let us consider only the two-dimensional spatial mobile distribution $(m=2)$. It is necessary to take $\nu=4$ in the model (2) for propagation conditions. In the case under consideration radio stations generally have equal power and omnidirectional antennas and employ broadband frequency filters at the receive input; these filters are transparent to signals on all the channels utilized by systems of the corresponding standard. Besides, these stations are emitters, are owned by independent users and are randomly and scatteredly distributed over the territory, which allows one to use the Poisson model of their distribution in the receiver vicinity.

Mobile usage patterns in these systems do not assume that any limitations are placed on signals of neighboring stations. Therefore it is interesting to discuss two possible scenarios of the situation [6]:

Scenario 1: The dynamic range D_P of emissions (signals) at an arbitrarily selected surface point $(H=1)$.

Scenario 2: The dynamic range D_P of emissions at the mobile location point or the signals dynamic range at the mobile receiver input (in receive mode, the mobile's own signal is absent (simplex operation mode) or is suppressed by the duplexer frequency filter $(H=2)$).

In the first scenario, the distribution (6) has no initial moments. Therefore it is possible to carry out systems analysis of the dynamic range of emissions at the selected point using (9); this analysis implies that we need

- to substantiate the required value of the prediction reliability coefficient p which is the probability that the emissions dynamic range will not exceed the desired value of D_{P0} ;
- to solve the equation (9) over D_{P0} analytically, using numerical methods or using the set of curves for the distribution (6).

In the discussed case, an analytical solution is possible: using the properties of the known representation of the incomplete gamma function of the second kind as

$$\Gamma(1+n, x) = n!\, e^{-x} \sum_{i=0}^{n} \frac{x^i}{i!}, \qquad n = 0,1,2,\ldots , \quad (11)$$

we have:

$$p = \Gamma\left(1, N_a D_{P0}^{-2/4}\right) = exp\left(-N_a \big/ \sqrt{D_{P0}}\right), \qquad \text{hence}$$

$$D_{P0} = \left(N_a / ln\ p\right)^2; \tag{12}$$

for $p \geq 0.9$ $\quad D_{P0} \approx \left(N_a / (1-p)\right)^2$.

For equal values of N_a the difference in values of D_0 for $p=0.9$ and for $p=0.99$ is approximately 20 dB.

In the second scenario, the distribution (6) for D_P also has no (initial) moments. Therefore, using (11), we reduce the equation (9) to:

$$D_{P0} = arg\left\{\left(1 + N_a \big/ \sqrt{D_{P0}}\right) exp\left(-N_a \big/ \sqrt{D_{P0}}\right) = p\right\}, \tag{13}$$

Numerical solution of this equation for $p=0.9$ and $p=0.99$ allows us, for instance, to a obtain the following estimations:

$$D_{P0}(0.9) \approx 3.54 N_a^2,\ D_{P0}(0.99) \approx 45{,}3 N_a^2; \tag{14}$$

the difference between these estimations for equal values of N_a is approximately 11 dB.

The parameter N_a in the given relationships represents the average number of mobile stations in transmit mode within the potential interfering interaction area with the radius R_{max} if the spatial mobile density within this whole area is the same and corresponds to the mobile density in the vicinity of the considered point. For conventional mobile stations (2-5W transmit power, 1.5 - 2.0 m antenna height above the surface) and assumed propagation conditions $(\nu=4)$ this area can be as large as 10-30 square kilometers (taking into account the interference of the direct and reflected rays, the shielding introduced by buildings and Earth surface, the effect of foliage etc). For mobile density $\rho \in [1000,10000]$ stations/square kilometer and relative mobile transmit time of 2-5% we obtain $N_a \in [200,10000]$, which generally corresponds to the most severe operation environment. For actual operation conditions, the spatial emitter density range may be assumed as $\rho \in [100,1000]$ stations/square kilometer, which approximately corresponds to $N_a \in [20,1000]$. For these conditions, the table below contains the expected space ranges for values of $D_0 = 10lgD_{P0}$ for $p=0.9$ and $p=0.99$ in accordance with (12) and (14).

Table 1	Scenario 1 ***(H=1)***		Scenario 2 ***(H=2)***	
ρ, stations /km^2	$10^2 \div 10^3$	$10^3 \div 10^4$	$10^2 \div 10^3$	$10^3 \div 10^4$
$D_0(0.9)$, dB	46÷ 80	66÷100	32÷66	52÷86
$D_0(0.99)$, dB	66÷100	86÷120	43÷77	63÷97

If in the second discussed scenario we define the dynamic range using the electromagnetic field strength and the analysis is based on the propagation model of the type (2) using the field strength and $\nu=2$, then the conditions are fulfilled for existence of the 1st (initial) moment in (8) for the distribution (6). For this scenario, $m_1(D_E)=N_a$. As a result of this, for the operation conditions discussed above we obtain the space range $20lg(m_1(D_E))=46 \div 80$dB for the interval $N_a \in [200, 10000]$ and the space range $20lg(m_1(D_E))= 26 \div 60$dB for the interval $N_a \in [20,1000]$.

The tentative estimations presented above do match the practical outlook on modern urban radio environment characteristics.

Signals dynamic range estimation for TDMA frequency channel

In TDMA systems signals of numerous space scattered radio stations sequentially fall into the main receive channel bandwidth of the receiver. The Figure 2 illustrates the time variation pattern of the signal level $P(t)$ in the receiver main receive channel for the TDMA network; the labels ***1,2,...,N*** on the pattern denote signals of each of N mobile

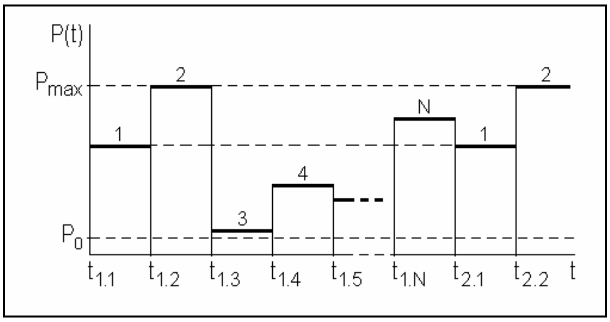

Fig. 2

stations. For $H=1$ the estimation of the probability that the dynamic range of signals from individual subscribers in the TDMA frequency channel will not exceed the value of the main receive channel dynamic range D_{mp} may be carried out on the basis of the following relationship which is a consequence of the model (6)-(8):

$$p\left(D < D_{mp}\right) \approx \left[exp\left(-N D_{mp}^{-m/\nu}\right)\right]. \tag{15}$$

Hence, for the receiver which carries out radio reception using the TDMA network frequency channel, the value of the main receive channel dynamic range D whose expected probability is equal to p is determined by the relationship

$$D \approx \left(-\frac{N}{ln\ p}\right)^{\nu/m}. \tag{16}$$

Table 2 contains estimated values of D for channels with $N=4$ (TETRA), $N=8$ (GSM) and $N=12$ (DECT) for different propagation conditions and two-dimensional emitter distribution $(m=2)$.

Table 2	p=0.9		p=0.99	
	ν=2	ν=4	ν=2	ν=4
D for **N=4**, dB:	16	32	26	52
D for **N=8**, dB:	19	36	29	58
D for **N=12**, dB:	21	42	31	62

Estimation of possible CDMA network cell shrinkage due to predominant signal presence

One of CDMA features is that cells can grow and shrink subject to existing load (traffic) [7]. The model (5) make it possible to relate CDMA network cell size variations to operating mobile stations spatial density variations.

If the maximum recommended (design) network load corresponds to Z subscribers simultaneously served by a cell ($Z \approx 13 \div 14$), then for nominal spatial subscriber density ρ_N the probability distribution, the mathematical expectation $m_1(R_S)$ and the variance $M_2(R_S)$ of the cell radius R_S can be determined according to (5) as:

$$w(R_S|\rho_N) = \frac{G^Z m}{\Gamma(Z)} R_S^{Zm-1} exp(-GR_S^m);$$

$$m_1(R_S|\rho_N) = \frac{\Gamma(Z+1/m)}{\Gamma(Z)G^{1/m}};$$

$$M_2\left(R_S|\rho_N\right) = \frac{\Gamma(Z+2/m)}{\Gamma(Z)G^{2/m}} - \left[\frac{\Gamma(Z+1/m)}{\Gamma(Z)G^{1/m}}\right]^2;$$

$$G = \rho_N a_m > 0, \quad Z \geq 1, \; m > 0, \quad R_S \geq 0.$$

Hence, for spatial subscriber density ρ_P that exceeds ρ_N and corresponds to the peak network traffic, the expected average cell size shrinkage $\Im$ may be determined as the ratio of mathematical cell size expectations for peak and nominal spatial subscriber densities:

$$\Im = \frac{m_1\left(R_S|\rho_P\right)}{m_1\left(R_S|\rho_N\right)} = \left(\frac{\rho_N}{\rho_P}\right)^{1/m}. \qquad (17)$$

For instance, if the spatial emitter density is increased by 2 times as compared to ρ_N then the average cell size radius will expectedly decrease by 1.41 times for two-dimensional subscriber distribution ***(m=2)*** and by 1.26 times for three-dimensional subscriber distribution ***(m=3)***, for example, in a multistoried building.

Prediction of maximum allowable radio environment complexity

The relationships (9),(10) make it possible to determine the maximum radio environment complexity which is allowable with regard to the probability that the receiver antenna input dynamic range will be exceeded by the input signals dynamic range. Taking into account the known incomplete gamma function representation (11), the equation (9) can be represented as:

$$p = \frac{\Gamma(H,Z)}{\Gamma(H)} = exp(-Z)\sum_{i=0}^{H-1}\frac{Z^i}{i!}, \quad Z = N_a D_{p0}^{-m/\nu}. \qquad (18)$$

Solution of this equation about D_{p0} for different values of N_a and for fixed values of ***p, H*** and ***ν/m*** makes it possible to estimate the highest average number of input signals N_a which may be allowed for the receiver whose antenna input dynamic range is equal to D_{in}.

CONCLUSION

The approaches presented above make it possible to predict in various scenarios the dynamic range of signals that create the radio environment at the observation point. The author tends to think that the material presented above has a potential for further development with regard to specific systems and provides opportunities for investigation of EMC problems in mobile communication systems.

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BIOGRAPHICAL NOTES

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