Mathematical model of single-channel signal search with two degrees of detection in radio frequency monitoring of mobile telecommunication systems

Anatolii Ilnytskyi[1], Oleg Tsukanov[2], Oleksandr Symonenko[3], Yuriy Pepa[4], Andrii Petrenko[5]

[1,2]National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”
37 Beresteysky Avenue, Kyiv, Ukraine, 03056
[3]Heroiv Krut Military Institute of Telecommunications and Informatization
St. 45/1 Knyazou Ostrozkih, Kyiv, Ukraine, 01011
[4,5]State University of Information and Communication Technologies
St. Solomyanska, 7, Kyiv, Ukraine, 03037
[1]anatolii.ilnytskyi@gmail.com, https://orcid.org/0000-0003-0454-1819,
[2]cukanov-o@ukr.net, https://orcid.org/0000-00027104-3274,
[3]lokalyt@gmail.com, https://orcid.org/0000-0001-8511-2017,
[4]yurka14@gmail.com, https://orcid.org/0000-0003-2073-1364,
[5]pab.05@ukr.net, https://orcid.org/0000-0002-4793-5474

Received 05.09.2024, accepted 18.10.2024
https://doi.org/10.32347/uwt.2024.15.1102

Abstract. Today, technical means of radio interception, monitoring and direction finding in mobile radio communication networks are implemented in the form of software and hardware complexes, the most important performance indicators of which are considered to be speed, detection accuracy and probability of recognition of mobile radio communication means with their information content.

At the same time, these issues still remain problematic and require further development of methods and techniques for searching and detecting signals of mobile radio communications in both frequency and time environments of telecommunication channels and their information processing.

The authors propose a mathematical model for searching for mobile radio signals in the frequency-time domain with two degrees of detection. The description of the mathematical model for determining the spectral components of signals in the frequency and time domains is carried out using the basic provisions of the theory of directed probability graphs, geometric probabilities with its well-known problem of meeting in a given time interval and the theoretical foundations of statistical information processing.

It is shown that the application of the mathematical model of single-channel search for signals of mobile radio communications with two degrees of detection in the frequency-time domain in practice will make it possible to determine the quality of the radio monitoring process and increase the efficiency of evaluating the spectral components of radio signals in terms of speed, detection

Anatolii Ilnytskyi Associate
Professor of the Department

Oleg Tsukanov
Associate Professor of the Departmen

Oleksandr Symonenko
PhD, Associate Professor

Yuriy Pepa
Ph.D., Associate Professor, Professor of the Department of Technical Systems of Cyber Protection DUIKT

Andrii Petrenko
Ph.D., associate professor, associate professor of the Department of Cyber Security of the National Aviation University

accuracy and probability of recognition of mobile radio communications with further determination of their information content.

Keywords: radio monitoring, telecommunication networks, mobile communication systems, performance indicators, speed, detection accuracy, recognition probability.

INTRODUCTION

It is known that radio frequency monitoring (RFM) of telecommunication systems (TCS) of fixed and mobile communications in Ukraine is entrusted to the State Enterprise 'Ukrainian State Centre of Radio Frequencies' (SE 'UCRF'), which continues its active development and becomes one of the largest and most powerful in Europe under martial law [1, 2]. Today, the technical means of radio interception, monitoring and direction finding in the networks of wireless fixed and mobile radio communication systems are implemented in the form of software and hardware complexes (SAC) of various modifications, which operate under conditions of partial or complete uncertainty of input signal parameters in real time against the background of a huge number and variety of radio emission sources (RES) with the most modern data transmission protocols [2]. Currently, the UCRC has more than 140 mobile and almost 200 stationary radio monitoring stations (RMNS) and SACs deployed in more than 100 settlements of the country [3]. The process of radio monitoring covers more than 200 thousand radio electronic devices (RED) of various purposes and subordination to both public and private structures. At the same time, all stationary RMS operate in automated modes, and their functional and technical capabilities fully comply with the requirements of the International Telecommunication Union [4,5]. Some models of mobile equipment and SACs, in particular, specialised RME. It should be noted that the most important indicators of the effectiveness of SAR in monitoring IEDs are speed, detection accuracy and probability of detecting mobile and fixed radio communications TCSs with further determination of their information content.

In the context of a full-scale invasion and combat operations for Ukraine's independence, the effectiveness of the RFEU's radio monitoring of TCS means is of particular importance. This is confirmed by the fact that under martial law, the State Enterprise 'UDCR' is subordinated to the Command of the General Staff of the Armed Forces of Ukraine, which ensures coordination of RFM, electronic and radar intelligence and electronic warfare of the state's power structures both on the territory of Ukraine and partially abroad. Therefore, the issues related to the development of new and improvement of existing technical means of RFM, further development of scientific and methodological apparatus and evaluation of their effectiveness, software and algorithmic support and practical implementation remain extremely relevant [6]. inconvenience lies in the fact that in the case of transmission of signals of several tones with the same amplitudes through a communication channel, their amplitudes will already be different at reception. This is mainly due to the uneven amplitude-frequency response of the RFI channel [3]. In addition, the equipment for generating multitone signals has an amplitude spread, which leads to a significant difference in the amplitudes of the received spectral components of the signal. Thus, according to the International Telecommunication Union's (ITU-T) Standardisation Sector specification, a DTMF receiver must operate with a twist (the difference between the amplitudes of the two main signal frequencies) of at least 8 dB. At the same time, it should not exceed 3 dB on the transmitting side [4].

PROBLEM FORMULATION

In the structure of the SAC monitoring system of MRC means, the main place is occupied by the subsystem of radio receiving devices (RRD), which solves the problem of signal detection in the frequency-time domain by cyclic procedures with one or more detection stages, implementing methods of sequential-parallel search and detection of signals. As an example, we can cite the mobile radio monitoring SAC MMS-02, which has the following technical characteristics [3]: radio frequency band: 30 MHz - 3000 MHz; sensitivity - not less than 0 dBμV/m (1 μV/m);

dynamic range - not less than 75 dB; maximum panoramic viewing speed - not less than 300 MHz/s; level measurement uncertainty - not more than 3 dB; frequency measurement accuracy - not less than 10-6.

The cyclic procedure for searching for MRC signals in the frequency domain with one degree of detection is described in [7]: the radio receiving device of the SAC is tuned to the frequency of a certain channel (1, 2, ..., N), where a decision is made on the presence or absence of a signal during a given analysis time t_a = const. In the absence of a signal, the receiver is tuned to the frequency of the next channel, and so on. When the last channel is reached, the radio is tuned to the frequency of the first channel and the search starts again. However, as practice shows, the signal may disappear during the time τ_c, for analysing N channels or appear when it is detected. At the same time, the moments of its appearance or disappearance may not coincide with the start or end of the RM of this channel. In addition, a signal in a channel may appear in the previous cycle of viewing the RPF of N channels. That is, there is a need to analyse the state and mathematically describe the signal search subsystem not only in the frequency but also in the time domain. At the same time, this procedure for searching for MRC signals in the frequency domain with one degree of detection, given in [7], was chosen by the authors of the article as a prototype. However, the analysis of the chosen prototype shows that the probability of successful completion of the search for a signal with one degree of detection in the frequency-time domain for a given time depends on the value of the signal duration τ_c, the number of analysed frequency channels N, the time of signal analysis in each channel t_a and the probabilities of the first F and second kind of errors D. Of these values, only the signal analysis time in each channel can actually be changed. That is, in order to increase the probability of successful completion of the signal search and reduce its time, it is necessary to reduce the signal analysis time t_a in each channel. For this purpose, we can propose the use of a cyclic procedure for searching for RSI signals with two (several) detection stages and different analysis times at each stage.

GOAL STATEMENT

The purpose and main content of the article is to describe a mathematical model of single-channel search for signals of mobile radio communications with two degrees of detection in the frequency-time domain. That is, the object of research in the article is the process of radio monitoring of radio emission sources of telecommunication networks and systems, and the subject of research is a mathematical model of single-channel signal search for mobile radio communications with two degrees of detection in the frequency-time domain. The application of the mathematical model in practice will make it possible to increase the efficiency of detecting the spectral components of radio signals and evaluate the procedure for searching for signals of MRC means in terms of speed, detection accuracy and recognition probability with further determination of their information content. It will also give an impetus to the further development of new and improvement of existing technical means of RFM, further development of the scientific and methodological apparatus for assessing their effectiveness, software and algorithmic support and practical implementation.

MAIN PART

The cyclic procedure for searching for mobile radio communication (MRC) signals in the frequency-time domain with one degree of detection (prototype) is schematically presented in the form of a directed probability graph (Fig. 1) and, using the theory of directed probability graphs, is described mathematically [7].

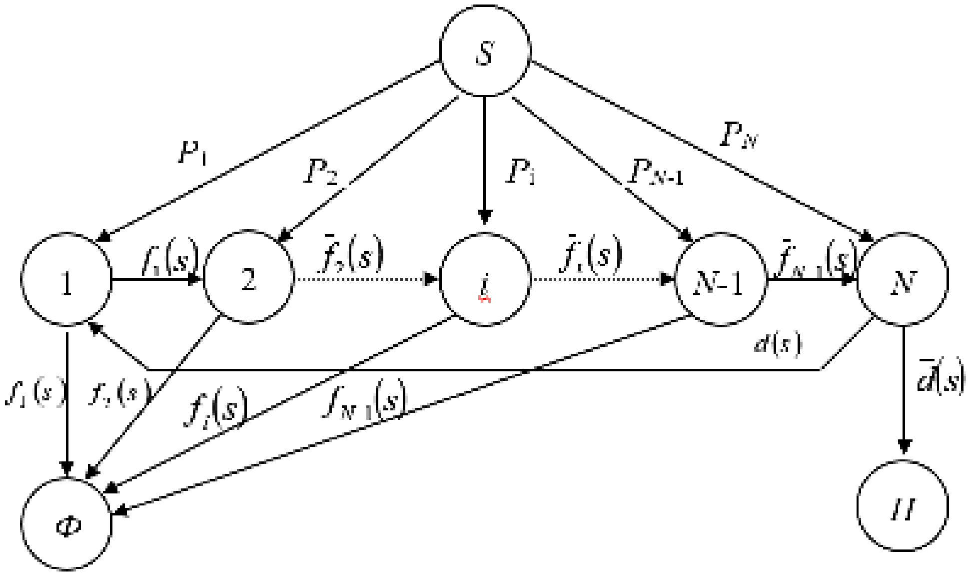

Fig. 1. Graph of the cyclic procedure of a single-channel search with one degree of detection

Here, the graph nodes represent possible states of the search subsystem: S is the initial state; H(s) is the absorption state corresponding to the successful completion of the signal search (correct recognition); F(s) is the absorption state corresponding to the false recognition of the signal. Graph edges represent possible transitions of the system from one state to another. Each edge of the graph has weights determined by (1), which take into account the probability of transition in one step from the state from which the edge leaves to the state it enters and the time spent in the corresponding state:

$$d(s) = De^{-t_a s}, \quad \bar{d}(s) = (1-D)e^{-t_a s}; \qquad (1)$$
$$f_q(s) = F_q e^{-t_a s}, \quad \bar{f}_q(s) = (1-F_q)e^{-t_a s},$$

And as given in [7], the probability of successful completion of the search for a given time with one degree of detection in the frequency-time domain is defined as:

$$P_{\text{П}}(t) = \frac{(\tau_c - t_a)(1-D)}{N(\tau_c + Nt_a)} \sum_{i=1}^{N} \sum_{n=0}^{\infty} \left(1 - \frac{(\tau_c - t_a)(1-D)}{\tau_c + Nt_a}\right)^n \times$$
$$\times (1-F)^{n(N-1)+N-i} h\left[t - (Nn + N - i + 1)\ t_a\right]$$
(2)

where F is the probability of false detection (first-order error) when analysing a cell with number N that does not contain a signal;
D - the probability of missing a signal (second-N);
h(x) - the Heaviside function;
t_a - the time of analysis of one cell;
τ_c - the duration of the input signal.

However, as practice shows, during the time t for analysing N channels, the signal may disappear or appear when it is detected. At the same time, the moments of its appearance or disappearance may not coincide with the moments of the beginning or end of the RM of this channel. In addition, a signal in a channel may appear in the previous cycle of viewing the MRC RRD of N channels. Also, analysing the above dependencies (2), we can conclude that to increase the probability of successful completion of the signal search and reduce its time, it is necessary to reduce the signal analysis time ta in each channel. For this purpose, we can propose the use of a cyclic procedure for searching for RSI signals with two stages of detection and different analysis times at each stage.

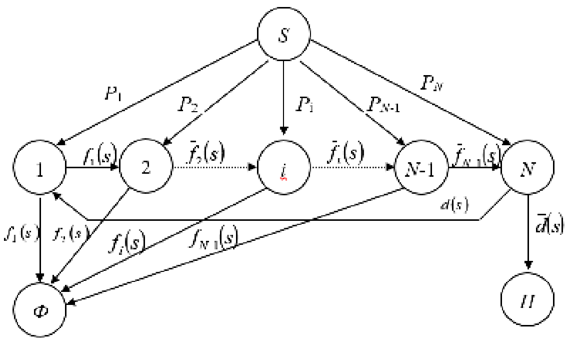

Fig. 2. Graph of a cyclic single-channel search procedure with two detection stages

In accordance with the above procedure of single-channel search with one detection stage (Fig. 1) and the description of the system state (2) for RM with two detection stages, we constructed (by analogy with [7]) a directed probability graph, which is schematically shown in Fig. 2.

As can be seen from Fig. 2, the first stage detects a signal in each of the N analysed channels within the time t_{a1}, which is less than the analysis time when searching with one stage of detection. If a signal is detected, the second stage is activated within the time t_{a2}, which is equal to the signal analysis time in a single-stage search. If a false signal detection occurs (first-order error F occurs) at the first stage, the search subsystem detects its own error during time t_{a2} and continues searching in the previous direction until it reaches the channel matching with the signal. If a signal is missed, a new search cycle begins. Thus, one of the conditions for a two-detection search is the inequality (t_{a1}+t_{a2}). The search for a signal can be completed either on the first cycle (when the search area is first viewed) or after some random number of cycles, and the duration of each cycle is a random variable due to the uncertain time spent on signal analysis. The time taken to analyse the signal in the *i*-th channel can have two values: t_{a1} and (t_{a1}+t_{a2}), respectively.

To search for MRC signals with two stages of detection, scanning DUTs can be used. That is, at the first stage, it is necessary to search for signals whose level exceeds a given detection threshold value (input signal level), and at the second stage, analyse only these signals. This approach is effective if some search channels do not contain any signal due to the limited analysis time at the first stage of detection. This situation can occur in the operation of an MRC with a dedicated or distributed control channel.

For the mathematical description of the above procedure, we will use the rules of graph transformation [8], and then the expressions for the functions of transition of the graph from the initial state S to the absorbing state H, which corresponds to the successful completion of the search (correct recognition), will be as follows:

$$H(s)=\frac{\bar{d}_1(s)\bar{d}_2(s)\sum_{i=1}^{N}P_i\prod_{q=i}^{N-1}\left[\bar{f}_{q1}(s)+f_{q1}(s)\bar{f}_{q2}(s)\right]}{1-\left[d_1(s)+\bar{d}_1(s)d_2(s)\right]\prod_{q=1}^{N-1}\left[\bar{f}_{q1}(s)+f_{q1}(s)\bar{f}_{q2}(s)\right]} \quad (3)$$

$$d_1(s)=D_1e^{-t_{a1}s},\quad \bar{d}_1(s)=(1-D_1)e^{-t_{a1}s}$$

$$d_2(s)=D_2e^{-t_{a2}s},\quad \bar{d}_2(s)=(1-D_2)e^{-t_{a2}s}$$

$$f_{q1}(s)=F_{q1}e^{-t_{a1}s},\quad \bar{f}_{q1}(s)=(1-F_{q1})e^{-t_{a1}s}$$

F_{q1}, F_{q2} are the probabilities of the first kind of error (false detection) when analysing a cell with number *q* (*q*=1, 2,..., N-1) that does not contain a signal at the first and second detection stages;

D_1, D_2 - probability of the second type of error (signal miss) when analysing a cell with number N at the first and second detection stages, P_i is the probability of starting viewing from the *i*-th cell (*i=1, 2,..., N*). Assuming that the search subsystem uses the same type of RRD and with a uniform distribution of signal occurrence moments within the search area, after providing H(s) in the form of a geometric series and performing the inverse Laplace transform $P^f_\Pi(t) = L^{-1}\{H(s)/s\}$, [8,9] (as in the case of search with one detection stage), the expression for the probability of successful completion of the search for a given time in the frequency domain with two stages will be as follows:

$$P_\Pi^f(t)=\frac{1}{N}\sum_{i=1}^{N}\sum_{n=0}^{\infty}\sum_{k=0}^{n}C_n^k(1-D_1)(1-D_2)D_1^k\left[(1-D_1)D_2\right]^{n-k}\times$$
$$\times\sum_{q=0}^{(N-1)n+(N-i)}C_{(N-1)n+(N-i)}^{q}(1-F_1)^q\left[F_1(1-F_2)\right]^{(N-1)n+(N-i)-q}\times$$
$$\times h\left[t-t_{a1}(Nn+N-i+1)-\right.$$
$$\left.-t_{a2}(Nn+N-i-q-k+1)\right] \quad (3)$$

where $C_n^k = \dfrac{n!}{k!(n-k)\,!}$

To calculate this probability, it is necessary in (4) for each i to sum all the components with indices n, q, k that satisfy the inequalities:

$$\begin{aligned} &t_{a1}(Nn + N - i + 1) + \\ &+ t_{a2}(Nn + N - i - q - k + 1) \le t \end{aligned} \tag{4}$$

As with the search for MRC signals with one detection stage, it is necessary to take into account, along with the frequency coincidence, the time coincidence in one channel of the desired signal and the RRD.

The description of the state of the single-channel subsystem for searching for MRC signals with two detection stages in the time domain is similar to the case of searching for signals in the time domain with one stage [7]. The peculiarity is that the duration of each search cycle will be a random variable due to the uncertainty of the time spent on signal analysis in each channel.

The time spent analysing a signal in one channel can also have two values: ta1 - in the case when only the first stage is involved, and (t_{a1}+t_{a2}) - in the case when two detection stages are involved. The transition from the first to the second stage occurs with probability F_1 when analysing an empty channel or with probability $P = (1 - D_1)$ when analysing a channel that holds a signal. With this in mind, the time of one search cycle T is defined as

$$T = t_{a1}N + t_{a2}(1 - D_1 + (N-1)F_1) \tag{5}$$

To calculate the probability of meeting an RRD and a signal during the analysis of N channels, we use the basic provisions of the theory of geometric probabilities similar to the case of a search with a single detection stage [7]. Then the time of signal analysis in one channel t_a in this case is a random variable, the average value of which, taking into account (6), will be determined by the expression:

$$t_a = \frac{T}{N} = t_{a1} + t_{a2}\,\frac{1 - D_1 + (N-1)F_1}{N} \tag{6}$$

To calculate the probability of meeting an RRD and a signal during the analysis of N channels, we use the basic provisions of the theory of geometric probabilities similar to the case of a search with a single detection stage [7]. Then the time of signal analysis in one channel t_a in this case is a random variable, the average value of which, taking into account (6), will be determined by the expression:

$$t_a = \frac{T}{N} = t_{a1} + t_{a2}\,\frac{1 - D_1 + (N-1)F_1}{N} \tag{7}$$

Taking into account (7), the expression for calculating the probability of successful completion of a search with two stages in the time domain in one viewing cycle can be written as follows:

$$P_\Pi^t = \frac{N(\tau_c - t_{a1}) - t_{a2}(1 - D_1 + (N-1)F_1)}{N[\tau_c + Nt_{a1} + t_{a2}(1 - D_1 + (N-1)F_1)]} \tag{8}$$

The fact of simultaneous signal detection in the frequency and time domains of the search can be considered as independent random events. In this case, taking into account (4), the expression for determining the probability of successful completion of the search for a given time in the frequency-time domain with two degrees of detection takes the form:

$$\begin{aligned} P_\Pi(t) = {} & \frac{(1-D_1)(1-D_2){P_\Pi^t}^2}{N} \sum_{i=1}^{N}\sum_{n=0}^{\infty}\sum_{k=0}^{n} C_n^k \left(1-(1-D_1)P_\Pi^t\right)^k \times \\ & \times \left[(1-D_1)P_\Pi^t\left(1-(1-D_2)P_\Pi^t\right)\right]^{n-k} \times \\ & \times \sum_{q=0}^{(N-1)n+(N-i)} C_{(N-1)n+(N-i)}^q (1-F_1)^q \left[F_1(1-F_2)\right]^{(N-1)n+(N-i)-q} \times \\ & \times h\left[t - t_{a1}(Nn+N-i+1) - t_{a2}(Nn+N-i-q-k+1)\right] \end{aligned} \tag{9}$$

To calculate this probability, it is necessary for each i to sum up all the components with indices *n, q, k* that Table 1 - Probabilities of successful completion of the search for a given time

According to the obtained relations (2) and (9), we calculated the dependences of the probability of successful completion of the search for a given time in the frequency-time domain on the search time for the case with one and two degrees of detection (Fig.3).

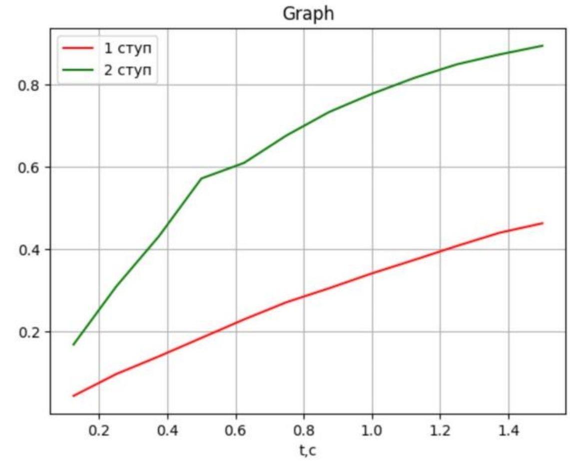

Fig. 3. Probabilities of successful completion of the search for a given time

When calculating these dependencies, the following were taken into account τ_c=100 мс, F_1= F_2= F_3=0,001, N = 8, the analysis time at each subsequent detection stage is 3 times longer than at the previous one. The total signal analysis time at all detection stages is ta = 40 ms. The probability of a signal miss at the last stage is assumed to be P = 0.1. The probability of signal miss at the previous stages was determined by the Neumann-Pearson criterion [8,9] at the given values of the probability of false detection. It was taken into account that the detection parameter (signal-to-noise ratio) is inversely proportional to the duration of signal analysis [10], and the signal is detected with random amplitude and phase.

The analysis of the obtained numerical values shows that to increase the efficiency of signal search, it is advisable to use cyclic search procedures with two (several) detection stages. At the same time, the introduction of the second stage makes it possible to increase the probability of successful completion of the search for a given time by an average of (2 - 2.5) times compared to the search with one detection stage, but the value of the probability of successful completion of the search increases slowly. To increase the probability of successful completion of the signal search and reduce its time, it is necessary to reduce the time of signal analysis ta in each channel. For this purpose, it is possible to propose the use of a cyclic procedure for searching for RMS signals with several (more than two) detection stages and different analysis times at each stage. However, these issues are beyond the scope of this article and can be considered separately.

CONCLUSIONS

1. The developed mathematical model of single-channel search for signals of mobile radio communications with two degrees of detection in the frequency-time domain makes it possible to calculate the probability of meeting an RRD and a signal during the analysis of N channels, i.e., during one viewing cycle перегляду $T= t_a N$, provided that the duration of the searched signal τc is not less than the analysis time of one channel $\tau_c \geq t_a$.

2. The probability of successful completion of the search for a signal with two degrees of detection in the time-frequency domain for a given time depends on the value of the signal duration τ_c, the number of analysed frequency channels N, the time of signal analysis in each channel t_a, and the probabilities of the first type of error F and the second type of error D.

3. The time spent on signal analysis in one channel can have two values: t_{a1} - in the case when only the first stage is involved, and $(t_{a1}+t_{a2})$ – in the case when two detection stages are involved. The transition from the first to the second stage occurs with probability F_1 when analysing an empty channel or with probability $P = (1 - D_1)$ when analysing a channel containing a signal.

4. The application of a mathematical model of single-channel search for signals of mobile radio communication means with two degrees of detection in the frequency-time domain in practice will make it possible to increase the efficiency of evaluating the spectral components of radio signals in terms of performance, detection accuracy and probability of recognition of mobile radio communication means (see Fig. 3) with the subsequent determination of their information content.

5. The direction of further development of scientific research in this subject area can be considered the analysis of the use of a cyclic procedure for searching RMS signals with several stages of detection (multi-stage detection) and different times at each stage of

detection and the synthesis of devices for practical implementation.

REFERENCES

1. **Ilchenko M. Iu., Narytnyk T. M., Kapshtyk S. V., Avdieienko H. L., Korsun V. I., Prysiazhnyi V. I.** (2013). Planuvannia ta elektromahnitna sumisnist v bezprovodovykh infokomunikatsiiakh: navchalnyi posibnyk dlia studentiv spetsialnosti 172 «Telekomunikatsii ta radiotekhnika». Kyiv, KPI im. Ihoria Sikorskoho, 259.
2. **Ilchenko M. Iu., Kravchuk S. O.** (2017). Telekmunikatsiini systemy. Kyiv, Naukova dumka Publ., 730.
3. CCITT Blue Book, Recommendation Q.23: Technical Features of Push-Button Telephone Sets. Geneva, (1989).
4. CCITT Blue Book, Recommendation Q.24: Multi-Frequency Push-Button Signal Reception. Geneva, (1989).
5. **IlnytskyiA.I., Zakharchuk L.V.** (2023). Problemni pytannia radiomonitorynhu dzherel i obiektiv telekomunikatsiinykh merezh i system ta zahalno-naukovyi kontseptualnyi pidkhid do yikh rozviazannia. III Mizhnarodna naukovo-tekhnichna konferentsiia «Systemy i tekhnolohii zviazku, informatsii ta kiberbezpeky: aktualni pytannia i tendentsii rozvytku», 30.11.2023. Viiskovyi instytut telekomunikatsii ta informatsii imeni Heroiv Krut, Kyiv, 2023, 167.
6. **Ilnytskyi A. I., Zakharchuk L. V.** (2024). Matematychna model odnokanalnoho poshuku syhnaliv zasobiv mobilnoho radiozviazku z odnym stupenem vyiavlennia v chastotno-chasovii oblasti. Kyiv, Viiskovyi instytut telekomunikatsii ta informatsii imeni Heroiv Krut, 71.
7. **Grimmett G. R., Stirzaker D. R.** (2001). Probability and Random Processes. New York: Oxford University Press Inc., 596.
8. **Hniedenko B. V.** (2010). Kurs teorii ymovirnostei. Kyiv, VPTs Kyivskyi universytet, 464.
9. **Ilnytskyi A. I., Stretovych O. V.** (2005). Alhorytmy dekoduvannia tonalnykh syhnaliv v kompleksakh rozvidky system rukhomoho radiozviazku. Trudy akademii, 65, 70–75.

Математична модель одноканального пошуку сигналів з двома ступенями виявлення при радіочастотному моніторингу телекомунікаційних систем мобільного зв’язку

Анатолій Ільницький, Олег Цуканов, Олександр Симоненко

Анотація. На сьогодні технічні засоби радіоперехоплення, моніторингу та пеленгування в мережах рухомого радіозв'язку реалізуються у вигляді програмно-апаратних комплексів, найважливішими показниками ефективності яких вважаються швидкодія, точність виявлення та вірогідність розпізнавання засобів рухомого радіозв'язку з їх інформаційним наповненням.

Разом з тим, ці питання все ще залишаються проблемними і потребують подальшого розвитку методів і засобів пошуку та виявлення сигналів рухомих засобів радіозв'язку як у частотному, так і в часовому середовищах телекомунікаційних каналів зв'язку та їх інформаційної обробки.

Авторами запропоновано математичну модель пошуку сигналів мобільного радіозв'язку в частотно-часовій області з двома ступенями виявлення. Опис математичної моделі визначення спектральних складових сигналів у частотній та часовій областях виконано з використанням основних положень теорії спрямованих графів ймовірностей, геометричних ймовірностей з її відомою проблемою зустрічі на заданому часовому інтервалі та теоретичних основ статистичної обробки інформації.

Показано, що застосування математичної моделі одноканального пошуку сигналів рухомого радіозв'язку з двома ступенями виявлення в частотно-часовій області на практиці дозволить визначити якість процесу радіомоніторингу та підвищити ефективність оцінювання спектральних складових радіосигналів за показниками швидкості, точності виявлення та ймовірності розпізнавання рухомих радіозасобів з подальшим визначенням їх інформативності.

Ключові слова: радіомоніторинг, телекомунікаційні мережі, системи мобільного зв'язку, показники ефективності, швидкість, точність виявлення, вірогідність розпізнавання