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PROPOSAL FOR REVISION OF RECOMMENDATION ITU-R SM.1880

Spectrum occupancy measurement

Introduction

Recommendation ITU-R SM.1880, on spectrum occupancy measurement, was adopted in 2011, while 2012 saw the adoption of Report ITU-R SM.2256, on spectrum occupancy measurements and evaluation, which contains a large volume of well-prepared additional material on the subject, in particular on the statistical processing of measurement data for the evaluation of spectrum occupancy. It would be very useful for Recommendation ITU-R SM.1880, in addition to referring to the ITU Handbook on Spectrum Monitoring (2011 edition), to contain references to Report ITU-R SM.2256, not least because the Report makes reference to the availability of detailed materials which supplement the provisions of the Recommendation.

Given that Annex 1 to Report ITU-R SM.2256 highlights the importance of the measurement results processing procedure for obtaining an accurate and reliable evaluation of frequency channel or band occupancy, it is proposed that the words “and evaluation” be included in the title of Recommendation ITU-R SM.1880, in the same way as in the title of Report ITU-R SM.2256.

The results of the analysis presented in Annex 1 to Report ITU-R SM.2256 can be used to clarify the provisions of § 3.4 “Accuracy and statistical confidence level” of Annex 1 to Recommendation ITU-R SM.1880 by making them clearer and more geared toward simplification of the procedure for measuring frequency channel or band occupancy over the whole range of occupancy values from 1% (and below) to 100%. At the same time, it is proposed that consideration be confined solely to the case of independent samples, setting aside the data for dependent samples as presented in § 3.4 of Annex 1 to Recommendation ITU-R SM.1880, since neither in this Recommendation, nor in Report ITU-R SM.2256, or in the Handbook on Spectrum Monitoring (2011), is there any mention of the characterizing features of such dependent samples, the factors influencing the dependency between the number of dependent samples and channel occupancy, and so on. Furthermore, scientific publications, for example [1], hold that there is no need to take account of the dependency between samples in measurements of spectrum occupancy.

The theoretical justification for the proposals to clarify the provisions of § 3.4 of Annex 1 to Recommendation ITU-R SM.1880 is set out in [2].

Proposal

The proposed draft revision of Recommendation ITU-R SM.1880 is set out in the Attachment hereto.

REFERENCES

[1] KIZIMA, S.V., KOZMIN, V.A., TOKAREV, A.V. – The advantages of using the absolute measurement error when estimating the occupancy of the radio-frequency spectrum // Measurement Techniques: Volume 55, Issue 5 (2012), Pages 568-573. SpringerLink: http://www.springerlink.com/openurl.asp?genre=article&id=doi:10.1007/s11018-012-0003-2

[2] KOZMIN, V.A, PAVLYUK, A.P., TOKAREV, A.B. [2014] – Optimization of requirements to the accuracy of radio-frequency spectrum occupancy evaluation. (The paper is in the process of publication in Russian in Electrosviaz Journal. See translation of the manuscript and later the article into English at the website: http://www.ircos.ru/en/articles.html)

ATTACHMENT

PROPOSED DRAFT REVISION OF RECOMMENDATION ITU-R SM.1880

Spectrum occupancy measurement and evaluation

(2011)

Scope

Although automatic occupancy measurement will not completely replace manual observations, it is still well suited for most cases. Frequency channel occupancy as well as frequency band occupancy should have a certain level of accuracy, in order to be compared or merged if necessary. By using the technique and proper method a more efficient use of existing equipment is possible.

The ITU Radiocommunication Assembly,

considering

a) that the increasing demand of radiocommunication services requires the most efficient use of the radio-frequency spectrum;

b) that good spectrum management can only satisfactorily proceed if the spectrum managers are adequately informed on the current usage of the spectrum and the trends in its demand;

c) that results of spectrum occupancy measurements would provide important inputs into:

– frequency allotments and assignments;

– verification of complaints concerning channel blocking;

– establishment of the degree of efficiency of spectrum usage;

d) that information obtained from frequency assignment databases does not reveal the degree of loading on each frequency channel;

e) that some administrations assign the same frequency to more than one user for shared use;

f) that it is desirable to compare measurement results from different countries in border areas or for instance in the aeronautical or maritime mobile services bands;

g) that automatic monitoring equipment is now in use by administrations, including methods for the analysis of records, and a number of parameters can be evaluated which are of considerable value in enabling more efficient utilization of the spectrum;

h) that in designing an automated system to gather occupancy data for use in spectrum management, one must determine what parameters are to be measured, the relationship among these parameters and how often measurements have to be taken to ensure the data are statistically significant;

~~j~~i) that measurement procedures and techniques should be harmonized to facilitate the exchange of measurement results between various countries;

~~k~~j) that successful merging or combining monitoring data not only depends on the data format in which the data is stored but also on the environmental and technical conditions under which the data is gathered,

recognizing

a) that various principles and methods of spectrum occupancy measurements are in use in the different countries;

b) that one particular method exists to get the high-accuracy frequency channel occupancy data and that such data usually is the basic to form the frequency band occupancy,

recommends

1 that the measurement procedures and techniques specified in Annex 1 should be used for spectrum occupancy measurements;

2 that both Report ITU-R SM.2256 and the ITU Handbook on Spectrum Monitoring in force should be used as guidance for ~~the~~ spectrum occupancy measurement and the equipment should satisfy the requirement mentioned in that Handbook;

3 that a common data format, that is a line-based ASCII file derived from the radio monitoring data format (RMDF), should be used following Recommendation ITU-R SM.1809.

Annex 1

1 Introduction

This Annex describes frequency channel occupancy measurements performed with a receiver or spectrum analyzer. The signal strength of each frequency step is stored. By means of post-processing the percentage of time that the signal is above a certain threshold level is determined. An example of the procedure for such post-processing is presented in Report ITU-R SM.2256 (Annex 1). Different users of a channel often produce different field-strength values at the receiver. This makes it possible to calculate and present the occupancy caused by different users.

2 Definitions

Frequency channel occupancy measurements: Measurements of channels, not necessarily separated by the same channel distance, and possibly spread over several different frequency bands to determine whether the channel is occupied or not. The goal is to measure as many channels as possible in a time as short as possible.

Revisit time: The time taken to visit all the channels to be measured (whether or not occupied) and return to the first channel.

Observation time: The time needed by the system to perform the necessary measurements on one channel. This includes any processing overheads such as storing the results to memory/disk.

Maximum number of channels: The maximum number of channels which can be visited in the revisit time.

Transmission length: The average length of individual radio transmission duration.

Integration time: Time interval for which an individual occupancy estimate is made. Normally 5 or 15 minutes.

Duration of monitoring: The total time during which the occupancy measurements are carried out.

Preset threshold level for measurement: If a signal is received above the threshold level, the channel is considered to be occupied.

Busy hour: The highest level of occupancy of a channel in a 60-min period.

3 Requirements

3.1 Equipment

Unchanged

3.2 Site considerations

Unchanged

3.3 Time related parameters

Unchanged

3.4 Accuracy and statistical confidence level

There is no linear relationship between accuracy and revisit time. In the case of measuring 100 channels with a revisit time of 1 s, which is a practical value, the number of channels can be increased to 1 000 with a revisit time of 10 s without affecting the confidence level/accuracy too much.

There is a linear relationship between the occupancy and the number of samples required to achieve a desired confidence level. The lower the occupancy, the more samples will be needed.

Table 1 compares independent sampling that is the simplest case using central limit theorem and dependent sampling using a first order Markov-chain differ little from many more complicated mathematical models.

Number of required independent samples versus spectrum occupancy at 10% relative accuracy and a 95% confidence level shown as Fig. 1.

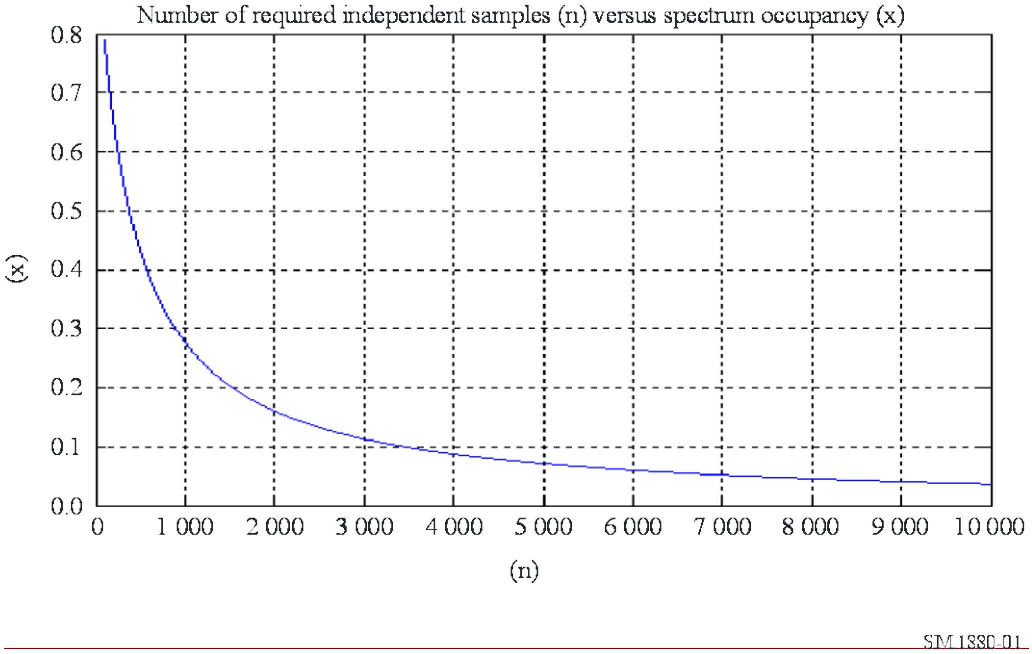
TABLE 1

Number of dependent and independent samples required to achieve 10% relative accuracy and a 95% confidence level at various occupancy percentages (assumes a 4 s sampling period)

Occupancy (%)	Number of required independent samples	Number of required dependent samples	Required hours of dependent sampling
6.67	5 368	16 641	18.5
10	3 461	10 730	12
15	2 117	6 563	7.3
20	1 535	4 759	5.3
30	849	2 632	2.9
40	573	1 777	2.0
50	381	1 182	1.3
60	253	785	0.9
70	162	166	0.2

FIGURE 1

Number of required independent samples versus spectrum occupancy at 10% relative accuracy and a 95% confidence level



3.4 Accuracy, statistical confidence level and required number of samples

In practice, the result of the collection and processing of data when conducting measurements of radio-channel (or frequency-band) occupancy is not in itself the true value of occupancy *SO*, but an estimate - a random variable whose values in individual measurement sessions, i.e. over the *integration time*, may deviate significantly from *SO*. The quality of the measurements is thus characterized by the accuracy Δ_{SO}, which determines the extent to which large deviations in the estimates from the true value *SO* are considered permissible, and by the confidence (confidence level) which indicates the minimum probability with which occupancy estimates must fall within the interval from $(SO - \Delta_{SO})$ to $(SO + \Delta_{SO})$, referred to as the confidence interval.

Even in cases where, during the *integration time*, the monitoring equipment provides only a small number of data samples, calculation of the occupancy estimate will give a number of values characterizing the radio-channel occupancy to a greater or lesser degree. However, such values will correspond to the true value of occupancy *SO* only when averaged over a large number of measurement sessions, while the values obtained in the majority of individual measurement sessions, i.e. during *integration times*, may deviate considerably from *SO*.

On the other hand, if used equipment is capable, over the *integration time*, to provide a number of samples considerably exceeding what is actually necessary, the accuracy and confidence of the measurements will be very high, but an excessive amount of computing resources will be consumed. Measurements therefore need to be performed with a somewhat optimum number of samples.

When considering issues related to the accuracy and confidence of occupancy measurements, a further difficulty lies in the fact that all of the values, i.e. the measured occupancy itself, errors (absolute and relative) and confidence level, are expressed as percentages. Work in this area therefore calls for particular attention.

To ensure sufficiently accurate and confident measurements with economical use of computing resources, account needs to be taken of the following.

The accuracy and confidence of occupancy estimates are determined not only by the number of samples obtained over the *integration time*, but also by the nature of the signals observed in the radio channel. The most exacting requirements in regard to the number of accumulated samples and operating speed of the monitoring equipment come into play in the case of radio channels with predominantly pulsed signals having duration of less than one thousandth of the *integration time*. This type of analysed signal is also characteristic when it comes to the measurement of frequency-band occupancy. In this case, the number of samples needed to produce accurate and confident measurements is determined, all other things being equal, by the actual level of channel occupancy. If, however, lengthy signals are observed in the radio channel, the required number of samples will depend primarily on the average number of signals observed during the *integration time*, and will generally be markedly lower than in the case of pulsed signals. Information and recommendations on occupancy evaluation for a channel with lengthy signals, and also for cases of unevenly timed sampling, may be found in Annex 1 to Report ITU-R SM.2256. Unless it is specified otherwise, we consider below the most unfavourable case involving the presence of pulsed signals.

Estimate accuracy requirements are normally expressed in the form of fixed-value limitations on the maximum permissible relative error (previous version of the Recommendation) or absolute error (Annex 1 to Report ITU-R SM.2256). Table 1 shows the outcome of calculating the number of independent samples required for ensuring a 10% relative and a 1% absolute measurement error according to radio-channel occupancy.

As can be seen from the table, a fixed (10%) limitation of the relative error for small occupancy values (lower than 5%) will lead to a significant increase in the required number of samples owing to the fact that, in this case, the resulting absolute error is very small. At the same time, ensuring a comparable degree of accuracy for large (over 30%) occupancy values calls for a very small number of samples. In contrast, a fixed (1%) limitation of the absolute error will lead to an increase in the required number of samples for large (greater than 20%) occupancy values, since in this case the resulting relative error displays low values. At the same time, ensuring such a degree of accuracy for a low level (less than 3%) of occupancy calls for a small number of samples.

TABLE 1

Number of samples required to achieve a maximum 10% relative error δ_{SO} or a 1% absolute error Δ_{SO} with a 95% confidence level

Channel occupancy, %	Required relative error $\delta_{SO} = 10\%$		Required absolute error $\Delta_{SO} = 1\%$	
	Resulting magnitude of absolute error, %	Required number of independent samples	Resulting magnitude of relative error, %	Required number of independent samples
1	0.1	38 047	100.0	**380**
2	0.2	18 832	50.0	**753**
3	0.3	12 426	33.3	**1 118**
4	0.4	9 224	25.0	**1 476**
5	0.5	7 302	20.0	**1 826**
10	1.0	**3 461**	10.0	**3 461**
15	1.5	**2 117**	6.7	4 900
20	2.0	**1 535**	5.0	6 149
30	3.0	**849**	3.3	8 071
40	4.0	**573**	2.5	9 224
50	5.0	**381**	2.0	9 608
60	6.0	**253**	1.7	9 224
70	7.0	**162**	1.4	8 071
80	8.0	**96**	1.3	6 149
90	9.0	**43**	1.1	3 459

In order to reduce the required number of samples over the entire range of occupancy variations, a possible solution is to combine these two approaches, i.e. for small occupancy values, make an estimate while limiting the permissible absolute error, and, for large occupancy values, while limiting the permissible relative error. If the transition from one type of limitation to the other is effected at the 10% occupancy level, the required number of samples will be determined by the values shown in bold type in Table 1, which is entirely acceptable from the practical standpoint.

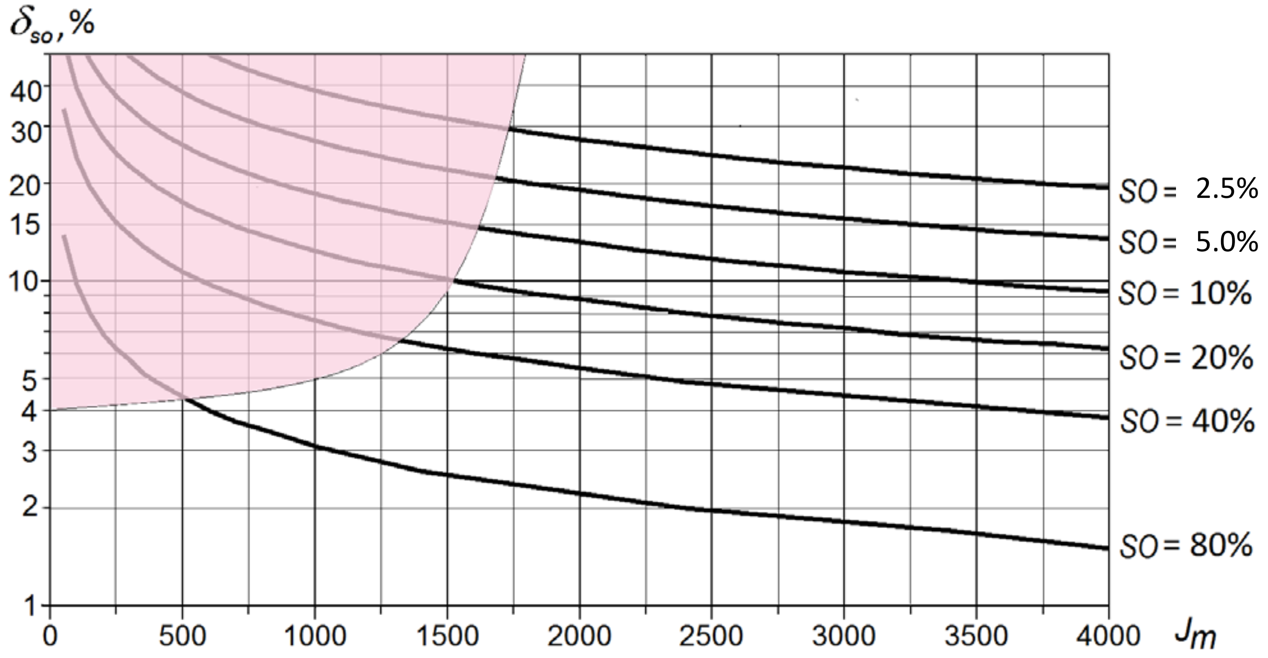
With this approach, the relative evaluation error increases for small occupancy values; however, from the practical standpoint, this can be entirely acceptable since the absolute evaluation error will then be small. Thus, for a 2% occupancy, the boundaries of the confidence interval at 1% and 3% corresponding to a 50% relative evaluation error nevertheless characterize an extremely low channel occupancy, making it hardly worthwhile to expend considerable additional computing resources to confirm this obvious fact with an additional accuracy amounting to no more than a few tenths of a per cent.

The meaning of the required number of samples as shown in bold type in Table 1 can be explained as follows. Where a channel for which there is no prior occupancy information is evaluated on the basis of 1 000 samples, the measurement accuracy for occupancy values in the order of 27% and 3% will be approximately as shown in Table 1, i.e. an approximate 10% relative error for 27% occupancy and an approximate 1% absolute error for 3% occupancy. Occupancy values greater than 27% will be measured with a lower (than 10%) relative error, while occupancy values lower than 3% will be measured with a lower (than 1%) absolute error. For radio channels with an occupancy from 3% to 27%, measurements will be characterized by a relative error exceeding 10% and an absolute error exceeding 1%.

Generally speaking, measurement errors for different occupancy values and differing numbers of processed data samples can be estimated using the graph shown in Fig. 1. The upper left-hand part of the graph is a shaded no-go area, signifying that to estimate occupancy with such a small number of samples is not recommended owing to an unacceptable increase in error.

FIGURE 1

Dependency of the relative error of occupancy estimates (δ_{SO}, %) on the number of accumulated samples (J_m) with a 95% confidence level for channels with pulsed signals



By analysing the dependencies, shown in Table 1, between the required number of samples and channel occupancy, it is easy to observe that among the values shown in bold type the most significant (3 461) corresponds to an occupancy of 10%. This means that by selecting, to be on the safe side, a somewhat higher value, for example 3 600 samples (corresponding to a sampling rate of four times per second over a period of 15 minutes), this can be used as the single universal number of samples for the entire range of occupancy variation from 1% (and below) to 100%. The measurement error will then be lower than 10% of the relative error for channels with an occupancy exceeding 10%, and lower than 1% of the absolute error for channels with an occupancy of less than 10%. A decrease in occupancy (from 10%) will be accompanied by a consequential decrease in the absolute estimation error, while an increase in occupancy (relative to 10%) will be accompanied by a consequential decrease in the relative error. Specific calculated values for the resulting errors are shown in bold type on the left-hand side of Table 2.

TABLE 2

Occupancy measurement errors corresponding to a 95% confidence level, achievable when estimating occupancy with exactly 3 600 and 1 800 data samples

Occupancy, %	Number of samples: 3 600		Number of samples: 1 800	
	Resulted absolute error, %	Resulted relative error, %	Resulted absolute error, %	Resulted relative error, %
1	**0.33**	32.5	**0.46**	46.0
2	**0.46**	22.9	**0.65**	32.3
3	**0.56**	18.6	**0.79**	26.3
4	**0.64**	16.0	**0.91**	22.6
5	**0.71**	14.2	**1.01**	20.1
10	**0.98**	**9.8**	**1.39**	13.9
15	1.17	**7.8**	1.65	**11.0**
20	1.31	**6.5**	1.85	**9.2**
30	1.50	**5.0**	2.12	**7.1**
40	1.60	**4.0**	2.26	**5.7**
50	1.63	**3.3**	2.31	**4.6**
60	1.60	**2.7**	2.26	**3.8**
70	1.50	**2.1**	2.12	**3.0**
80	1.31	**1.6**	1.85	**2.3**
90	0.98	**1.1**	1.39	**1.5**

In the vast majority of cases, it is entirely possible to use half the number of samples, i.e. 1 800 samples, as a single universal number, corresponding to a sampling rate of twice per second over a period of 15 minutes, thereby allowing for the use of slower equipment. The calculated values of the resulting errors for 1 800 samples are shown on the right-hand side of Table 2. Where 1 800 samples are used instead of 3 600, the absolute estimation errors increase by a factor of $\sqrt{2} \approx 1{,}41$, while exceeding by a relative error of 10% for small occupancy values begins not at 10% but at 17%. Nevertheless, with 1 800 samples, the corresponding absolute error values remain relatively small, differing from the 3 600 case only by tenths of a per cent, this being altogether acceptable for practical purposes. Furthermore, as can be seen from Fig. 1, the resulting relative error values for 1 800 samples do not lie within the no-go area, confirming their acceptability.

As already mentioned above, the values shown in Table 2 correspond to the occupancy measurement of channels with pulsed signals. For channels with lengthy signals, the absolute estimation errors are inversely proportional to the number of processed samples and, as can be seen from Fig. 2, can be significantly smaller than for pulsed signals. Where it is a known fact that precisely such signals are occurring within the channel, the number of samples can be reduced to 600, as can be seen from the data in Table 3, which presents the calculated values of the relative and absolute errors according to channel occupancy and the ratio τ_s / T_I, where τ_s is the duration of each lengthy signal, which are considered to be equal in the model used, and T_I is the *integration time*. From Table 3 it can be seen that the measurement errors diminish considerably as the relative duration of lengthy signals increases.

FIGURE 2

Absolute error Δ_{SO} of a spectrum occupancy estimate with a 95% confidence level, in the case of 1 800 samples for pulsed signals in channel (1), or 500 (2), 250 (3), 100 (4) or 30 (5) lengthy signals in the channel over the integration time

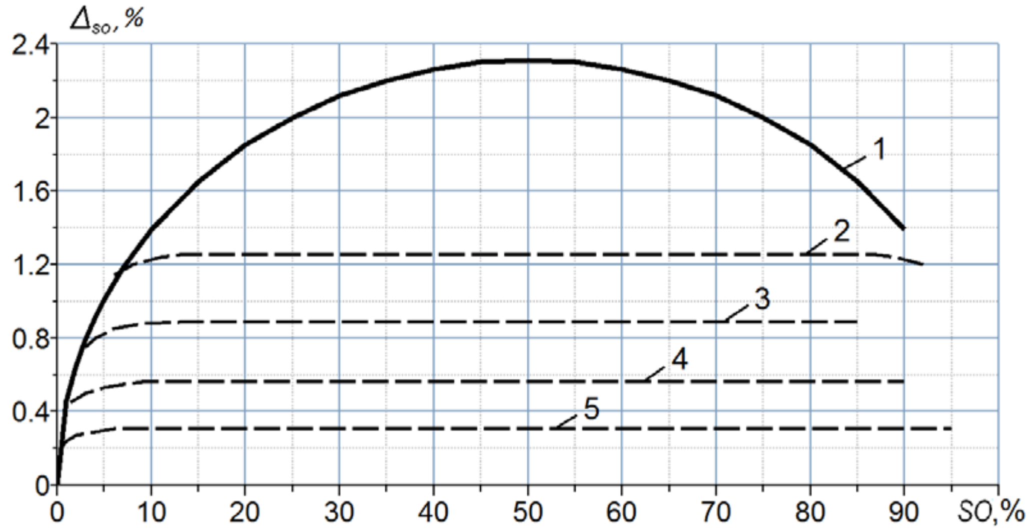


TABLE 3

Error corresponding to the confidence level of 95% observed when estimating occupancy in a channel with lengthy signals of a duration not less than the specified value of the ratio τ_s / T_I = 0.0025 for 600 data samples

Channel occupancy, %	τ_s / T_I = 0.0025		τ_s / T_I = 0.01	
	Resulted absolute error, %	Resulted relative error, %	Resulted absolute error, %	Resulted relative error, %
1	**0.34**	33.64	**0.17**	16.82
2	**0.48**	23.79	**0.24**	11.89
3	**0.58**	19.42	**0.29**	9.71
4	**0.67**	16.82	**0.34**	8.41
5	**0.75**	15.04	**0.38**	7.52
10	**1.06**	**10.64**	**0.53**	**5.32**
15	1.30	**8.69**	0.65	**4.34**
20	1.50	**7.52**	0.75	**3.76**
30	1.84	**6.14**	0.92	**3.07**
40	2.13	**5.32**	1.06	**2.66**
50	2.38	**4.76**	1.19	**2.38**
60	2.61	**4.34**	1.30	**2.17**
70	2.81	**4.02**	1.41	**2.01**
80	3.01	**3.76**	1.50	**1.88**
90	3.19	**3.55**	1.60	**1.77**

In conclusion, it is to be noted that by using the concept of "floating" error requirements when estimating an occupancy, it is possible not only to considerably reduce the number of samples required but also to propose three fixed values for the number of samples, which can serve as universal values for the entire range of occupancy values from 1% (and lower) to 100%. This should considerably simplify the work of operators when measuring frequency channel or band occupancy.

3.5 Considerations on occupancy measurements

Unchanged

3.6 Presentation and analysis of collected data

Unchanged