Radiocommunication Study Groups

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PROPOSED REVISION TO RECOMMENDATION ITU-R SM.1880

Spectrum occupancy measurement and evaluation

Introductory remarks

Some provisions of Recommendation ITU-R SM.1880-2 do not accurately reflect the specifics of performing occupancy measurements in cases where the average duration of signals in channels exceeds the interval between the moments of testing their state, i.e. the samples characterizing the state of the channel turn out to be dependent. In particular, the Table 1 given in Annex 1 of Recommendation ITU-R SM.1880-2 in the part relating to the case of the presence of dependent samples is not universal, because the values given in it depend on the characteristics of the signal in the radio channel and on the rate of testing the condition of the examined radio channel. It is proposed to reflect this factor which needs to be taken into account when carrying out measurements, in the new version of Table 1 and give some explanations to it.

The values added to the new version of Table 1 are calculated according to the methodology described in the article by SPAULDING, A.D., HAGN, G.H. [August 1977], indicated in the "References to Annex 2" section at the end of the Recommendation ITU-R SM.1880-2. Explanations on the need for adjustments and convenient calculation formulas are presented in the article: Tokarev A.B., Kozmin V.A., Pavlyuk A.P., Polev V.Yu. Duration of data collection when measuring occupancy of stationary radio channels. *Systems of Control, Communication and Security*, 2024. Nº 1. https://sccs.intelgr.com/arch.html. (In Russian. The English translation is available on the website: https://www.ircos.ru/en/articles.html).

The following are draft revisions of the indicated paragraphs of Recommendation ITU-R SM.1880-2:

– 3.4 of Annex 1;

– 2.2 of Annex 2; and

– literature to Annex 2.

Figure 1 of Appendix 1 has been slightly modified and is presented in better quality.

For contacts: Dr. Vladimir Kozmin, kv@ircoc.vrn.ru

3.4 Accuracy, statistical confidence level and required number of samples *(from Annex 1)*

From a statistics point of view, the result of spectrum occupancy measurement is an estimate or statistical value, thus it has accuracy and reliability attributes. Accuracy reflects the control of error, usually measuring with relative accuracy or relative error as well as absolute error, and reliability indicates the confidence of the result marking with confidence level. Measurement itself can be deemed as a sampling process from a given population, and result analysis is essentially as a process of estimating the population using the limited samples.

In practice, the result of the collection and processing of data is abbreviated as *SO*, but it is not a true value as just mentioned. 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 integration times, while the individual evaluations may deviate considerably from *SO*.

On the other hand, under computer control it is possible to collect a large number of samples, more than is necessary for determining occupancy with the required accuracy. There is an optimum number of samples, beyond which additional data may not significantly improve results. The optimum number of samples needed is discussed in the current Report ITU-R SM.2256.

~~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.~~

The quality of the measurements is characterized by the absolute 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. It is sometimes more convenient to define the confidence interval limits in the form $SO \cdot (1 \pm \delta_{SO})$, where $\delta_{SO} = \Delta_{SO} / SO$ is the maximum permissible relative evaluation error.

When limiting the permissible relative measurement error ~~T~~there is ~~a linear~~ the following relationship between the occupancy and the number of samples required to achieve a desired confidence level~~:~~. ~~T~~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. Calculations were performed in accordance with the methodology presented in [1]. The numerical values in the table correspond to the case when the interval between samples (sampling period) is $T_R \approx 1$ second. At a similar rate of the occupancy measurement, when testing radio channels in which the average duration of individual radio transmissions is less than 1 second, the samples can be considered independent; and in channels with an average transmission length exceeding 1 second, the samples turn out to be dependent. Explanations to the table are given in paragraph 2.2 of Annex 2.

~~The quality of the measurements can also be characterized by the absolute 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. It is sometimes more convenient to state the~~

~~confidence interval limits in the form $SO \cdot (1 \pm \delta_{SO})$, where $\delta_{SO} = \Delta_{SO} / SO$ is the maximum permissible relative evaluation error.~~

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 −1 s sampling period)

Occupancy (%)	Number of required independent samples	With an average transmission duration of about 1.5 seconds		With an average transmission duration of about 12 seconds	
		Number of required dependent samples	Required hours of dependent sampling	Number of required dependent samples	Required hours of dependent sampling
6.67	5 368	16 641	4.6	128 910	35.8
10	3 461	10 730	3.0	83 112	23.1
15	2 117	6 563	1.8	50 837	14.1
20	1 535	4 759	1.3	36 861	10.2
30	849	2 632	0.72	20 388	5.7
40	573	1 777	0.5	13 760	3.8
50	381	1 182	0.32	9 149	2.5
60	253	785	0.22	6 076	1.7
70	162	502	0.15	3 890	1.1

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

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 the case of channels with pulsed signals, the number of samples required to produce accurate and confident measurements is determined, all other things being equal, by the actual level of channel occupancy, as can be seen from Table 2.

TABLE 2

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 δ_{SO} = 10%		Required absolute error Δ_{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

As can be seen from Table 2, a fixed (10%) limitation of the relative error value for low occupancy (less than 5%) will lead to a significant increase in the required number of samples due to the need to ensure a small resulting absolute error. At the same time, providing a comparable level of accuracy for high (over 30%) occupancy requires only a small number of samples. On the contrary, a fixed (1%) limitation of the absolute error value will lead to an increase in the required number of samples for high (more than 20%) occupancy due to the small resulting relative error. At the same time, ensuring this level of accuracy for occupancy values of less than 3% requires only a small number of samples.

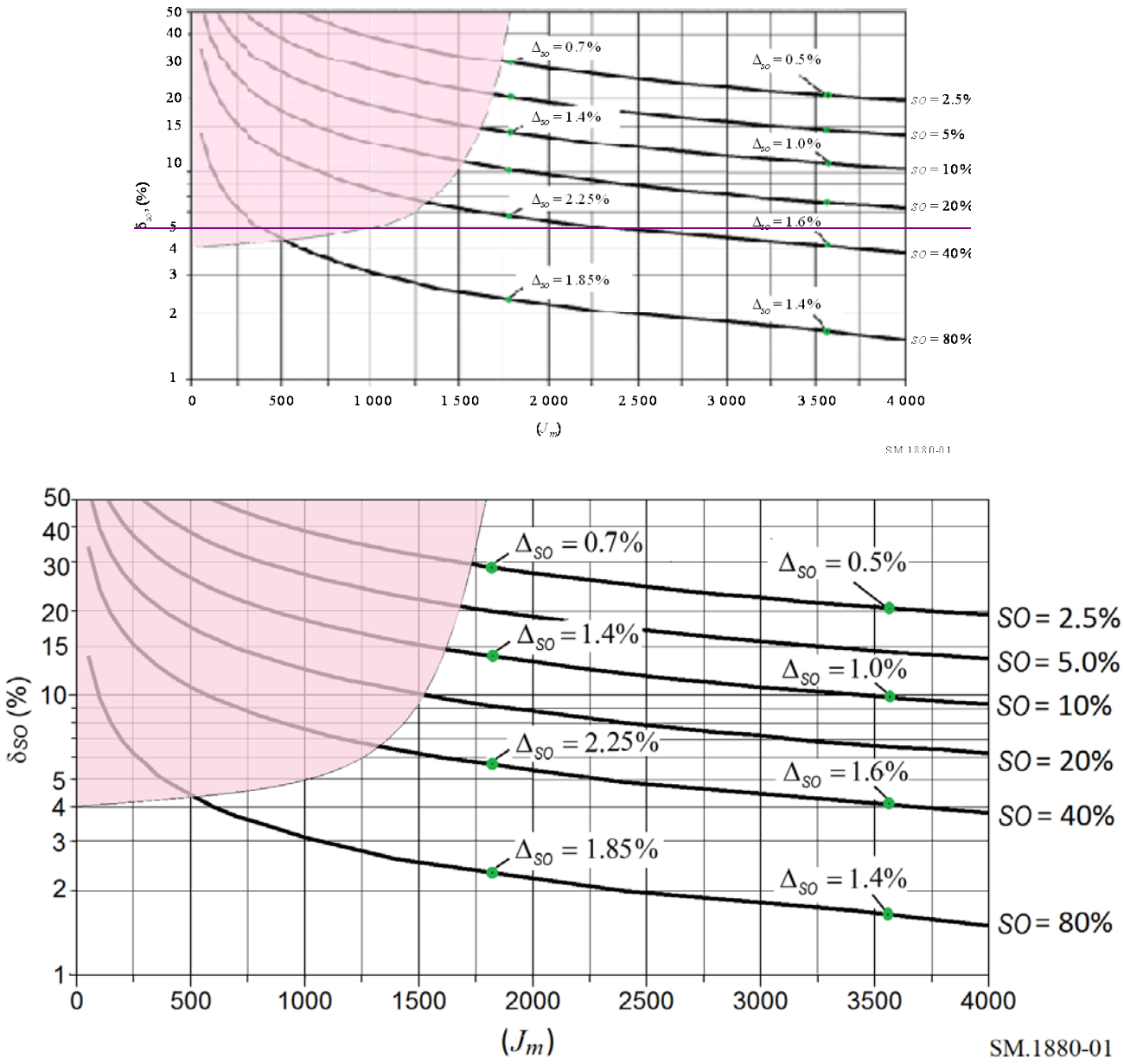
A possible solution that will minimize the required number of samples over the entire range of occupancy values is a characterization in which the permissible relative error is normally limited for high occupancy, and the permissible absolute error is limited for low occupancy. In the case of a transition from one type of restriction to another with an occupancy value of 10%, the required number of samples will be determined by the values highlighted in bold in table 2, which is acceptable from a practical point of view.

Measurement errors for different occupancy values and differing numbers of processed data samples can be estimated using the graph shown in Fig. 1. Green dots at curves indicate values of absolute errors for some particular numbers of samples, particularly for ~~1600~~ 1 800 and 3 600. The upper left-hand part of the graph is a shaded inadvisable area, signifying that to estimate occupancy with such a small number of samples is not recommended owing to an unacceptable increase in error. More detailed information may be found in Annex 1 to Report ITU-R SM.2256.

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. Suggestions on occupancy evaluation for channels with lengthy signals may be found in Annex 1 to Report ITU-R SM.2256.

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



2.2 Dependent sampling *(from Annex 2)*

For dependent sampling, the sequence can be represented by a Markov-chain of first order. Although more complicated mathematical models can also be used, for the situations of interest to monitoring, the results from such complex models differ little from first-order Markov results [1]. ~~The resulting number of required samples for an accuracy of 10% and 95% confidence level for various occupancy figures are given in Table 1 in Annex 1 to this Recommendation. It can be seen that the number of required dependent samples is about three times higher than with independent sampling~~When measuring occupancy based on dependent samples, the number of samples required to meet the requirements for accuracy and reliability should be increased in relation to the required number of independent samples [1]. The correction factor determining the increase in the number of samples is approximately 2 times higher than the ratio q of the average duration of transmissions in

the radio channel to the interval of monitoring the channel state (revisit time or sampling period). For example, at q = 1.5, the value of the required correction factor turns out to be close to three, and at q = 12, the number of samples and the time of data collection will need to be increased by about 24 times in relation to the case of independent samples (see Table 1 of Annex 1 to this Recommendation). It should be noted that at T_R = 1 sec the values of the q parameter will coincide with the quantities of the average transmission duration.

REFERENCE~~S TO ANNEX 2~~

[1] SPAULDING, A.D., HAGN, G.H. [August 1977] – On the definition and estimation of spectrum occupancy. IEEE Trans. In EMC, Vol. EMC-19, No. 3, p. 269-280.