## Communications Research Centre

THE DETERMINATION OF DAILY USAGE OR OCCUPANCY IN THE LAND-MOBILE BAND 138-174 MHZ AT MONTREAL
by
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# COMMUNICATIONS RESEARCH CENTRE 

DEPARTMENT OF COMMUNICATIONS
CANADA

## THE DETERMINATION OF DAILY USAGE OR OCCUPANCY IN THE LAND-MOBILE BAND 138 - 174 MHZ AT MONTREAL

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# THE DETERMINATION OF DAILY USAGE OR OCCUPANCY IN THE LAND-MOBILE BAND 138-174 MHZ AT MONTREAL 

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#### Abstract

From the monitoring of signal levels in the land-mobile bands over a period of 10 consecutive days, it is shown that the base-station levels remain constant within $\pm 2 d B$ and can be used for isolating station occupancy from that due to mobiles. It is also shown that a monitoring period of 4 to 5 days gives reliable estimates of; 1) the mean daily occupancy and 2) the $75 \%$ level of the cumulative distribution of occupancies measured in 5,30 or 60 minute periods. Only a few ( $8 \%$ ) of the frequencies showed a systematic difference of occupancy between the morning and afternoon values and it was found that there was no statistical difference between the occupancy of a frequency monitored for 5 minutes every 10 minutes and and for 5 minutes every 30 minutes.


## 1. INTRODUCTION

The use of radio communications within the land-mobile bands by police, taxis, construction companies, etc. has become a necessary part of the structure of modern society. However, the high growth rate of land-mobile users has resulted in numerous complaints of channel congestion, suggesting the need for more spectrum space than is currently available. For Montreal, Toronto and Vancouver in Canada, practically all frequencies in the land-mobile bands have been assigned and, if more users are to be added to the system, then either the spectrum space has to be increased or sharing must take place.

Even if the spectrum space were to be increased by, say $10 \%$, at the expense of other services, at the present growth rate it too would soon be fully occupied. Hence, the sharing of channels would only be postponed for the short term. In essence, space in the land-mobile bands is too valuable to allow one user in a given area to have the sole use of a particular frequency which he only uses for a low percentage of the time.

If sharing is to be applied on a systematic basis, then a knowledge of occupancy or usage of a frequency throughout the day is a must. Since this knowledge was not available for Canada, steps were taken to remedy this situation, in the first instance for Montreal, Quebec in March, 1977 This report is concerned with the sampling strategy that should be adopted in order to obtain reliable estimates of occupancies in the land-mobile bands, in particular in the frequency range 138.0 to 174.0 MHz .

Experimental details including the selection of frequencies to be monitored are discussed in Section 2.

The stability of base-station signal levels are investigated in Section 3, and an overview of the degree of congestion in the land-mobile band $138-174 \mathrm{MHz}$ at Montreal is presented in Section 4.

Occupancy parameters based on channel usage during a day are developed in Section 5, along with correction values based on the number of days during which monitoring was carried out.

The possibility that a user, for a short period within the day, might need a much higher value of occupancy than that given by the average over the day is considered in Section 6.

In Section 7 the occupancies over the morning and afternoon hours are compared in case it might be possible to share a channel with users that compliment each other in their requirements.

In Section 8 occupancy parameters derived from data where a frequency is monitored for 5 minutes every 10 minutes and that for monitoring for 5 minutes every 30 minutes are compared.

Conclusions and suggestions with respect to a monitoring scenario are presented in Section 9.

## 2. EXPERIMENTAL DETAILS

### 2.1 MONITORING SITE

The data used in this report were obtained from monitoring frequencies in the land-mobile band in the range 138.0 to 174.0 Mhz at the Montreal district monitoring station at St Remi, Quebec. This station is 24 km south of Montreal city. This site was chosen because Montreal was suffering from channel congestion and because the site at St Remi, about three hours drive from Ottawa, had a suitable garage in which the monitoring van could be locked-up over night and had a suitable receiving antenna mounted on a 48 m tower. The antenna was a log-periodic antenna (Andrew 29-005), vertically polarized with a gain of 8 dB and oriented with maximum gain in the direction of Montreal city.

### 2.2 MONITORING EQUIPMENT

The monitoring unit ${ }^{1}$, supplied by Stanford Research Institute, consists of a receiver under the control of an Interdata 70 (now $7 / 16$ Perkin Elmer) computer. The frequencies to be monitored are entered into scan tables with a maximum of 250 frequencies per scan table. For a given scan table, the receiver is tuned in turn for each frequency in the scan table and the amplitude of the signal on that frequency is recorded in $\mathrm{dB} \mu V$. Allowing for the settling time of the receiver and sample time, it takes 2 ms to sample each frequency. Thus, one scan of the frequencies takes up to 0.5 s . The process is repeated 600 times over a period of 5 minutes. This set of 600 samples for each of up to 250 frequencies is referred to as a raster. On the completion of a raster, the next scan table is utilized and the procedure repeated. The signal levels monitored are written out on magnetic tape for subsequent data reduction and analysis. About 116 rasters (covering 9.5 hours of monitoring) can be stored on a $730 \mathrm{~m}(2400 \mathrm{ft})$ reel of magnetic tape at 800 BPI .

### 2.3 DATA REDUCTION

Preliminary data reduction is carried out on the Interdata computer under control of a Fortran program. With this program, the signal levels recorded on magnetic tape are read and sorted into distributions (of signal levels) between -36 and $90 \mathrm{~dB} \mu V$ for each frequency, as shown in Figure 1. From this figure, it will be noted that the signal levels can be divided into three areas defined by the noise level and the peak boundaries. All signals below the noise level, $-\mathrm{Hl} \mathrm{dB} \mu V$ in this case, are assumed to be due to noise and are recorded when neither the mobiles nor base-station are transmitting. The signal levels within the peak boundaries, ( 45 to $49 \mathrm{~dB} \mu V$ here) are due to a base-station transmissions. All other signal levels are due to mobile transmissions. Algorithms have been developed for determining the noise level and peak boundaries from the distribution. The algorithm for the peak boundaries is based on the fact (see Section 4) that the signal levels for a base-station are very constant, within a few dB , whereas those for mobiles can vary over a considerable range.

The occupancy or usage of a particular frequency can be determined as either threshold occupancy or station occupancy where:
(i) Threshold occupancy is defined as the ratio of the number of monitored signal levels equal to or greater than the noise level to the total number of observations. It is expressed as a percent and
(ii) Station occupancy is defined as the ratio of the number of monitored signal levels equal to or within the peak boundaries to the total number of observations. It is also expressed as a percent.


Figure 1. Distribution of signal levels at 163.41 MHz measured from 0800 to 1730 hrs . Threshold occupancy is $27 \%$. Base-station occupancy is $13 \%$.

With respect to base-station transmissions, it should be noted that, if there are several base-stations all transmitting simultaneously on the same frequency, the strongest signal tends to dominate and, in general, only one peak will be obtained. On the other hand, if these same base-stations are transmitting independently, more than one peak will be observed. Unless otherwise stated in this report, station occupancy will also refer to the sum of the individual station occupancies if there is more than one peak.

In addition to the above program, a second program is used to read in the data from the tape again in order to find the threshold and station occupancies for each raster. It takes a full day of monitoring to accurately obtain the levels, but these can then be used against individual rasters to get raster occupancies. These occupancies are referred to as 5 -minute occupancies.

Finally, the information per frequency on the distribution of signal levels, noise level, peak boundaries, threshold, station occupancies and similar information for the 5 -minute values are written to another magnetic tape for further investigation. This reduced data is about $1 / 20$ of the volume of the monitored data.

As will be mentioned in the next section, for the data discussed here only two scan-tables were used, so that, for a given frequency, a 5 -minute occupancy is derived every 10 minutes; i.e., a sampling period of 10 minutes.

### 2.4 SELECTION OF FREQUENCIES FOR MONITORING

In November 1976 an overview of the occupancies of all frequencies in the land-mobile band in the range 138.0 to 174.0 Mh 数 was obtained by monitoring these frequencies (about 1000) at the Montreal monitoring station for two days. From these data, all frequencies with a threshold occupancy $\geq 5 \%$, on any one of the two days of monitoring were selected for a more detailed monitoring in March 1977. A list of 488
frequencies was obtained. These frequencies were set up into 2 scan tables and were monitored between the hours of 0800 and 1730 hours for 10 consecutive week days from March 2 to March 15. Approximately 35,000 observations per day were made on each frequency.

At that time, a monitoring plan along the lines adopted by Stanford Research Institute ${ }^{2}$ was envisaged. This plan included the monitoring of not only base-station but also mobile transmissions. Hence the frequencies selected for detailed monitoring included the mobile frequencies of duplex systems. Subsequently, it was decided to adopt the method described by Burke ${ }^{3}$. For this method, the transmissions from mobiles are ignored on the grounds that they cannot be obtained with any degree of reliability and only the occupancies of base-stations are determined. Consequently, only those frequencies with base station transmissions have been studied.

For the Montreal district, at that time, there were 618 base-station frequencies and it was found that 354 of these were included in the 488 frequencies monitored during March 1977. As discussed in the next section, 238 of the 354 frequencies were selected for detailed investigation with respect to the choice of sampling strategy to be adopted.

Except as stated in Section 8, all occupancies discussed in this report are for station occupancies and, for convenience, are referred to as:
(i) daily occupancy, which is the sum over one day of all station occupancies on a particular frequency,
(ii) average occupancy, which is the average of daily occupancies observed over several days and
(iii) maximum occupancy, which is the highest value of daily occupancy observed over severable days.
(iv) 5-minute occupancy, which is the total station occupancy over a 5 minute period.If there is more than one station observed on a given frequency, the occupancies are summed.

## 3. BASE-STATION SIGNAL LEVEL STABILITY

A 10-day average distribution per frequency was derived by merging the 10 days of signal level distributions for each frequency and finding the set of average peak locations. This was to see if there was sufficient stability in peak location from day to day for peaks to be reinforced and to remain clearly defined. It was found that in the last 2 days' data, the signal levels for all peaks were lower than for the previous 8 days, (particularly on the loth day) producing doubling of peaks on the average distributions in many cases. It was felt that this was due to an equipment fault during days 9 and 10 . Accordingly, an 8 -day average distribution per frequency was formed from the first 8 days of data, and used as a reference throughout the analysis. For the 488 frequencies the number of average peaks per frequency are shown in Table 1.

From this distribution it can be seen that only $488-250=238$ frequencies exhibited base station activity over the 8 days. However, it should be noted that the average distribution need not represent all peaks on the contributing distributions. A single peak of moderate height appearing on one day may not survive as a separate peak on the 8 -day average. Peaks on this average distribution tend to be peaks which appeared at nearly the same levels in most runs, or else appeared once or twice with

TABLE 1.
Distribution of base-station peaks

| number of peaks | number of frequencies |
| :---: | :---: |
| 0 | 250 |
| 1 | 206 |
| 2 | 26 |
| 3 | 6 |
| total | 488 |

sufficiently high counts to survive as peaks after averaging over the full eight day period. This means that a frequency with, say, I peak on the average distribution may have 0 or any number of peaks on any individual day's distribution.

For each of the 238 frequencies with peaks on the 8 -day average the signal levels of the average peak were compared with those for the peaks in the daily distributions. The shifts in peak signal levels of the daily distributions from those of the average distributions were derived for each day. For shifts $>10 \mathrm{~dB}$ it was considered that the peaks were independent. The distribution of all shifts in all runs is shown in Figure 2. There were about 2000 peaks considered. It was found that $97 \%$ of corresponding peaks have signal levels within $\pm 2 \mathrm{~dB}$ of the level on the cumulative run. Data from days 9 and 10 were excluded from this analysis.


Figure 2. Distribution of the difference in signal levels of each daily peak level of a frequency from its corresponding mean over 8 days. The distribution contains approximately 2000 values and $97 \%$ of these values are within $\pm 2 d B$ of the mean.

Of the 238 frequencies, there were 19 frequencies with 25 peaks where shifts were 5 dB or greater. For these 19 frequencies, a comparison of their appropriate daily distributions with their average distributions showed that, all but three of the 25 shifts could be explained on the basis of multiple peaks due to many users sharing the frequency. Where there are many minor peaks, one peak with counts greater than the others is often identified in the peak selective algorithm as the only base peak. When the occupancies of the users vary from day to day, the base peak appears to shift in signal level, while the actual shift has been in occupancy between users. The remaining 3 shifts were $+5,+9,+5 \mathrm{~dB}$.

Peaks can therefore be considered generally stable in signal level within $\pm 2 \mathrm{~dB}$. Of 238 frequencies with 8 observations each, there were 3 peaks which showed single shifts $>5 \mathrm{~dB}$, for which there is as yet no explanation.

## 4. OVERVIEW OF STATION OCCUPANCY

For determining station occupancy it was decided to use only these records for the 238 frequencies which showed peaks on the 8 -day average. The fact that these peaks survived in the averaging process suggested that, in general, similar base-station activity would occur from day to day. However, it should be noted that station occupancy is not a function of signal level provided, obviously, that its level is above threshold. For days 9 and 10 the drop in signal level did not take any of the base-station peaks on the above 238 frequencies below threshold so these days were included in the analysis for station occupancy.

The 238 frequencies can be considered as a sub-set of the set of 618 Montreal frequencies with base station listings on the Montreal data file. Those of the 618 frequencies not among the 238 frequencies either had $<5 \%$ total occupancy in November so that they were not monitored in March, or else had such low average occupancy in March that they did not survive as base station frequencies on the 8 -day average. In either case, for these 380 frequencies, daily occupancy is taken as zero. Figure 3 shows the cumulative distribution of 10 -day average occupancy for the 238 frequencies alone, and for the 238 frequencies considered as part of the 618 Montreal frequencies with base-station listings. For example, the average occupancy is $30 \%$ or less for $94 \%$ of all frequencies with base-station listing or for $84 \%$ of the 238 frequencies with peaks on the 8 -day average.

The results shown in Figure 3 do not appear to support the earlier remarks concerning congestion in the Montreal area. However, it should be noted that frequencies allocated for emergency services cannot be shared and, in general, tend to show low occupancies. Even so, the monitoring results did indicate to the Montreal District, Office that there were many more frequencies available for sharing than they had expected. To be fair, in 1977 the Montreal monitoring station only had chart recorders to monitor 2 frequencies a day for their activity and the biggest problem was which 2 frequencies to monitor. In 1978, a similar overview of station activity was taken at Acton monitoring station (near Toronto). From this site it is possible to monitor all stations within 80 miles. The results obtained were similar to those in Figure 3 for Montreal, much to the surprise of the Ontario Regional Office.

## 5. CORRECTION VALUES FOR AVERACE AND MAXIMUM OCCUPANCY

As defined in section 2, average occupancy is the average of the values of daily occupancy observed over several days and maximum occupancy is the highest value of daily occupancy observed in the same period. The question addressed in this section is how many days of monitoring should be carried out


Figure 3. Cumulative distribution of the 10-day average occupancies; - for the 238 frequencies on which base-stations were observed and $x$ for the full set of 618 frequencies, 380 of which had zero occupancy.
to derive reliable estimates of these parameters. To facilitate this work it is assumed that the average occupancy over the 10 days is equal to that of the parent population and can be used as the reference standard. Likewise, the highest value of daily occupancy observed over the 10 days is also a reference standard. Basically, the assumption implies that monitoring for more than 10 days will not give a more reliable estimate.

It will be remembered that, although only the first 8 days of data could be used to judge base-station signal stability, all $\mathbf{1 0}$ days of data can be used for determining occupancy.

### 5.1 Average Method

For the results presented below it was argued that, if say a t-day monitoring period was adopted then, in a 10-day period, monitoring conld commence on any one of the first 7 days and 7 sets of average occupancies would be obtained. The worse case situation per frequency would be that value for which the calculated average occupancy was the lowest of the 7 possible values. The difference between this lowest value and that from the 10 -day average could be regarded as a correction value, which if added to any to any one of the 7 values, would result in a value of average occupancy for that frequency which would be equal to or greater than the parent mean with $100 \%$ probability. Similar correction values can be found for the other 237 frequencies.

Of course, having individual correction values for the Montreal site is of little value for data at other sites. However, if it is assumed that the spread of correction values is independent of the monitoring site then, a particular level can be selected from the distribution of these values and used with other results.

The confidence levels selected are the $75 \%$ and $95 \%$ values; the $100 \%$ level is unrealistic. The choice of $75 \%$ level is recommended if the observed occupancies are to be used as a criteria for sharing. For this value the probability that the average value will be less than the parent population is $25 \%$ or 0.25 , and the probability of mismatch with another user is $0.25 \times 0.25=0.0625$, or $6.25 \%$, which is an acceptable level. The cumulative distribution of the correction values for all occupancies are shown in Figure 4. From this figure the $\mathbf{7 5 \%}$ and the $95 \%$ confidence levels of the correction values can be determined for a 4-day monitoring period.

From the Montreal data the correction values at the $75 \%$ and $95 \%$ levels for monitoring schemes involving 1 to 5 days are shown in Table 2. The values are for all occupancies and for those occupancies $\leq 20 \%$, where sharing is most likely to be applied.

For an application of the values shown in Table 2, if, over a 4-day monitoring period, the average station occupancy is $\leq 20 \%$ then, for a $75 \%$ level of confidence, a value of 2 units of percent occupancy is added to the average value. The resultant value will be equal to or greater than the parent mean with a $75 \%$ probability.


Figure 4. Cumulative distribution of the correction values derived for a 4 -day monitoring scheme and are for all occupancies. The $75 \%$ confidence level is $4 \%$.

## TABLE 2.

Correction values to be added to average occupancies for various monitoring periods.

|  | all occupancies |  | occupancies $\leq 20 \%$ |  |
| :---: | :---: | :---: | :---: | :---: |
| days | $75 \%$ | $95 \%$ | $75 \%$ | $95 \%$ |
| 1 | 8 | 15 | 6 | 14 |
| 2 | 5 | 13 | 4 | 9 |
| 3 | 4 | 11 | 3 | 7 |
| 4 | 4 | 9 | 2 | 5 |
| 5 | 3 | 7 | 2 | 4 |

### 5.2 Maximum Method

The arguments for this method follow on the same lines as that for the average method except that, for each frequency, the highest value of daily occupancy observed in a given monitoring period is used instead of the average value.

Using the 4-day scheme as an example, the highest daily occupancy of the 4 days is retained. Over the 10 day period, 7 such values will be found for each frequency. The highest value of this set is taken as the population maximum for that frequency, i.e. it is assumed that if monitoring was continued for many more days no value of daily occupancy obtained would be greater than this highest value. From the same set of 7 values, the lowest value is taken as the worse case situation. The difference between this value and the highest value is the correction value.

An alternative way of looking at this is to assume that the 10 values of daily occupancy per frequency are arranged in ascending numerical order. The highest value is that for the parent population and, for a 4 -day scheme, the 4 th value of this set is the worse case value.

The cumulative distribution of the correction values for the Montreal data, for a 4 -day scheme, is shown in Figure 5 for all occupancies.

As for the average method, distributions of the above correction values for monitoring periods of 1 to 5 days were derived and the $75 \%$ and $95 \%$ confidence levels determined. The results are shown in Table 3.

TABLE 3.
Correction values for the maximum method for various monitoring periods.

|  | all |  | occupancies | occupancics $<20 \%$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| days | $75 \%$ | $95 \%$ | $75 \%$ | $95 \%$ |  |
| 1 | 17 | 41 | 15 | 44 |  |
| 2 | 14 | 30 | 11 | 35 |  |
| 3 | 11 | 25 | 0 | 24 |  |
| 4 | 9 | 22 | 7 | 22 |  |
| 5 | 7 | 15 | 5 | 19 |  |



Figure 5. Cumulative distribution of the correction values for the maximum method.

## 6. VARIATION IN STATION OCCUPANCY THROUGHOUT A DAY

### 6.1 INTRODUCTION

In the previous section it was tacitly assumed that daily occupancy was a reasonable measure for estimating the usage of a channel or frequency. However, during the course of a day the user may, in the short term of 5 to 60 minutes, require the use of the channel for a much greater percentage of the time than that indicated by the average over the day. In this case, it could be argued that a higher level than daily occupancy should be assumed for sharing criterion. It will be remembered that daily occupancy is the average of the 5 -minute occupancies.

An example of the variation in 5-minute occupancy over the course of a day is shown in Figure $6(\mathrm{a})$ for a particular station occupancy observed for 5 minutes every 10 minutes. To avoid confusion with observed zero 5 -minute occupancy, missing data is indicated by an X. For this particular case monitoring did not start until 0820 and there were equipment problems around 1030 hours. As shown in this figure, activity can vary considerably over a 10 minute period, e.g. from $60 \%$ to $0 \%$ occupancy around 1730 hours. If the activity of this station is followed for the next 3 days, as shown in Figures 6(b), (c) and (d), the same type of rapid fluctuations appears in a somewhat random fasfion across the day. For these 4 days the daily occupancy varied from $9 \%$ to $20 \%$ with a mean of $15 \%$, which questions the use of the daily occupancy as a parameter for sharing purposes when, at times, the user requires $60 \%$.


Figure 6. Station-occupancy observed for 5 minutes every 10 minutes from 0800 to 1800 hrs on 139.71 MHz . The symbol $x$ indicates missing data.
(a) day 1, (b) day 2 ,
(c) day 3 ,
(d) day 4.

### 6.2 OCCUPANCY PARAMETER FROM 5-MINUTE VALUES

A suitable occupancy parameter can be determined from the 5 -minute values if the cumulative distribution of these values is derived, as shown in Figure 7, and a particular confidence level selected. Consistent with the previous work, the $75 \%$ and the $95 \%$ levels are used here. For these levels the occupancies are $25.5 \%$ and $53.5 \%$ and their ratios with respect to the average occupancy are 1.5 and 3.5, respectively. For convenience, these ratios are referred to as the R75 and R95 ratios.

Similar results for other base-stations were also found and the cumulative distributions of the R75 and R95 ratios are shown in Figures 8. For the former, the ratios vary from 1.0 to 2.0 with a value of 1.76 at the $95 \%$ confidence level. The R95 ratios show a much wider range of values, 1.0 to 5.0 , with a value of 4.2 at the $95 \%$ level of the distribution.


Figure 7. Cumulative distribution of the 5 -minute values from Figure 6. The $75 \%$ confidence level is $25.5 \%$ occupancy and the $95 \%$ level is $53.5 \%$. The average value is $15.5 \%$.


Figure 8. Cumulative distribution of the R75 and R95 ratios for days 1 to 4. The $95 \%$ confidence level of the R75 distribution is 1.76 , that for the R95 distribution is 4.2.

### 6.3 THE R75 AND R95 RATIOS

The results shown in Figure 8 are for days 1 to 4 . Consistent with the results found for average and maximum occupancy, it was found that the $95 \%$ confidence levels of the R75 and R95 ratios varied with the number of days in a monitoring run and with the particular days used. The variation of this level for R75 ratios is shown in Figure 9 as a function of the number $(N)$ of days in a monitoring run. The smooth curve is drawn through the mean of these values. It will be noted that, if 3 or more days are used for finding the ratios, the mean of the $95 \%$ levels remains essentially constant (within $3 \%$ ) with respect to the value of 1.73 for the parent population obtained from the 10 days of data. Also, the spread of values for a particular monitoring period is relatively small (i.e. about $\pm 5 \%$ ). It should be noted that, in practice, the R 75 ratio should be determined for each station to be considered for sharing. On the other hand, the factor 1.73 is very useful for estimating from the mean occupancies the total spectrum still available for sharing purposes.


Figure 9. The $95 \%$ levels of the cumulative distribution of the $R 75$ ratios obtained over $N$ days.

It could be argued that, for sharing purposes, trying to cater to the current user by considering his occupancy in intervals of 10 minutes is over-generous and that his average use in 30 minutes or 60 minutes should be the prime factor. To this end, the above work was repeated using these intervals for obtaining the R75 and R95 ratios. The results were very similar to those given above, in that if 3 or more days were used for obtaining the distribution, the $95 \%$ levels remained fairly constant. The values from the R 75 ratios for each of the 10,30 and 60 minute intervals are shown in Table 4 for $\mathrm{N}=10$ days. As would be expected, the factor decreases with increasing time-interval used for averaging. In

TABLE 4.
$95 \%$ confidence level of the cumulative distribution of the R75 ratios for all average occupancies and for those $>20 \%$. $N=10$ days.

| interval(minutes $)$ | average $\geq 0 \%$ | average $>20 \%$ |
| :---: | :---: | :---: |
| 10 | 1.73 | 1.69 |
| 30 | 1.64 | 1.51 |
| 60 | 1.58 | 1.44 |

deriving these averages over 30 or 60 minutes, running averages were used in order to keep the number of samples approximately the same as those for 5 -minute samples.

It would be expected that the ratios of Table 4 would be a function of average occupancy as they asymtotically approach unity for $100 \%$ occupancy. This was confirmed by considering only those cases (56) for which the average occupancy was $>20 \%$. The results are included in Table 4.

The $95 \%$ confidence levels of the R95 ratios for 10,30 and 60 minute intervals are shown in Table 5. However, it is considered that these factors are overly cautious and should not be used.

TABLE 5.
$95 \%$ confidence level of the cumulative distribution of the R95 ratios for all average occupancies and for those $>20 \%$. $N=10$ days

| interval(minutes) | average $\geq 0 \%$ | average $>20 \%$ |
| :---: | :---: | :---: |
| 10 | 4.5 | 3.3 |
| 30 | 3.1 | 2.4 |
| 60 | 2.7 | 2.2 |

## 7. DIURNAL VARIATION

This section is concerned with the possibility of a user showing systematic variation in occupancy over the course of a day. Thus he might be very active in the morning and very inactive in the afternoon. In this case it would be possible to share this user with one who had the opposite activity in time, e.g. a morning and evening newspaper service. This type of service could be said to have an 8 hour diurnal period. Other possible periods would be 2 -hour and 4 -hour.

For reasons given below only the 8 -hour diurnal variation is considered here and this variation is considered between the hours 0800 to 1200 and 1300 to 1700 . The period 1200 to 1300 hours was ignored because it was found in general that usage dropped considerably during this period (lunch hour). The test used was the deviation given by:

$$
\text { Deviation }=(\mathrm{AM}-\mathrm{M}) / \mathrm{M}
$$

where $A M$ is the morning occupancy and $M$ is the mean of the morning and afternoon occupancies. A positive value of deviation indicted higher occupancy in the morning than in the afternoon.

An example of an 8-hour variation is shown in Figure $10(\mathrm{a})$ and has a deviation of -0.08 . This figure corresponds with the 5 -minute values of Figure 6(a). From Figure 10(a), it can be seen that there is negligible diurnal variation. However, for the same situation on the following day, as shown in Figure $10(\mathrm{~b})$, there is a relatively high degree of diurnal variation as indicated by the value of 0.50 deviation. If the 4 days are averaged, the diurnal variation is reduced as shown in Figure 10(c), the deviation is -0.42 . For 10 days of data, the variation is further reduced to a deviation of -0.33 as shown in Figure 10 (d). The occupancy is about $10 \%$ in the morning and $20 \%$ in the afternoon.


Figure 10. A comparison of station occupancy oltained over two periods 0800-1200 and 1300-1700 hrs for frequency 134.71 MHz . The dashed line is the mean of these two periods.
(a) Day 1 with deviation of -0.08 ,
(b) Day 2 with deviation of -0.56 ,
(c) Days $1-4$ with deviation of -0.42,
(d) Days 1-10 with deviation of -0.33 .

If all of the stations are examined for their 8 -hour deviation over the 10 days, the results are as given in Table 6. It will be seen there that only $8 \%$ ( 19 stations) have a deviation $\geq|0.3|$. Of these 19 stations, 16 were found to be positive and 16 (not necessarily the same) had a mean occupancy $>20 \%$.

From the above results, it is concluded that the inclusion of 8 -hour diurnal variation as an additional feature in the decision to share a channel with a new user is not worth the trouble for the amount of spectrum that may be gained. If a deviation of $\geq|0.3|$ is arbitrarily considered large enough for diurnal variation to be taken into account only about $8 \%$ of the channels are available. However, considering the other constraints on channel allocation (EMC, allocation plan etc.), this value is too low to make it worthwhile. In addition, an estimate has to be made of the expected diurnal variation

TABLE 6.
Percent distribution of the magnitude of the deviation about the mean occupancies.

| deviation |  |  |
| :--- | :--- | ---: |
| $\|0.0\|$ | to | $\|0.1\|$ |
| $0.1 \mid$ | to | $\|0.2\|$ |
| $\|0.2\|$ | to | $\|0.3\|$ |
| $0.3 \mid$ | to | 35 |

It follows that, if the relatively simple case of 8 -hour diurnal variation has little to recommend itself for channel sharing, then the rather more complex cases of 2 -hour and 4 -hour periods have even less to contribute. While some large values of deviation were obtained for these periods, they were relatively few and the problem of estimating the diurnal variation of a new user to fit these cases becomes practically impossible. It was for this reason that the 2 -hour and 4 -hour periods were ignored in this report.

## 8. SAMPLING PERIOD

As mentioned in Section 2, the data used here were sampled for 5 minutes every 10 minutes. This 10 minutes is referred to as the sampling period and arose because the frequencies to be monitored were contained on 2 scan tables. For the Montreal district, there are about 1000 base station frequencies in the three land-mobile bands to be monitored. For technical reasons, the scan tables should only contain frequencies from one band. Consequently, the frequencies to be monitored will be distributed over 6 scan tables, where each scan table contains from 150 to 206 frequencies. If all scan tables are included in a monitoring run, the sampling period will be about 24 minutes. The results presented in this report were obtained from data monitored for a 10 -minute sampling period. For a 24 -minute sampling period, there is a danger that the data would be undersampled and that the conclusions arrived at from a 10 -minute sampling period would be invalidated.

To simulate the effect of increasing the sampling period, use was made of the 5 -minute occupancies (both threshold and station) of which, on the average, about 48 values were obtained per day per frequency. Two subsets, each of 24 values, were then formed by taking the values sequentially from the 48 values and allocating them alternatively to the first and second subset respectively. Each set of values can then be regarded as that obtained for a sample period of 20 minutes. The means and standard error of the mean of each set were computed and a Student $t$ statistic for the difference of these means computed (Pugh and Winslow ${ }^{5}$ ). In essence, the $t$ statistic is the differences of the means divided by the square root of the sum of the squares of the standard errors. A small value of $t$ indicates that the two means obtained are not significantly different from the mean of the 48 values and occurs if the difference of the means is small or their standard crrors are large.

Five days of the data taken in March 1977 were each subjected to the Student t test. This test not only included the threshold occupancies of all frequencies in the scan tables, but also the station occupancy of those frequencies for which there were 1 and 2 peaks on the day chosen. In all cases, the differences obtained were not significant at the $5 \%$ confidence level. Thus, a sampling period of 20 minutes is sufficient to obtain a reliable estimate of the average daily occupancy.

To extend the test to a 30 -minute sampling period, 3 subsets of 16 values each were formed from the 48 values of 5 -minute occupancy obtained per frequency, where the time interval between each value of a subset was 30 minutes. It should be remembered that a value of 5 -minute occupancy is obtained every 10 minutes. Only the first two subsets were subjected to a Student $t$ test. The third subset was
discarded. Again, it was found that the difference of the means of the two sets was not significant at the $5 \%$ confidence level. Hence, it can be concluded that a 30 minute sampling period ( 2 samples per hour) throughout the day, is sufficient to obtain a reliable estimate of the average daily occupancy.

For a 30 -minute sampling period, 1 value per period would have the same distribution throughout a day as that obtained from a 10 -minute sampling period, if the distribution is random. Thus, the R75 ratio should be independent of the sampling period. This was confirmed by repeating the work of Section 6 using only 1 of 3 consecutive values of the set. The results shown in Table 7 were independent of whether the first, second or third-value of the set were used. For completeness, both 10 -and 30 -minute values are shown in the Table for the 30 minute period but these are identical.

## TABLE 7

Comparison of the results shown in Table 4(10-minute values) and those obtained by using only 1 of 3 consecutive values of the set.

| period | 10 -minute |  | 30 -minute |  |
| :---: | :---: | :---: | :---: | :---: |
| occupancy | $\geq 0 \%$ | $>20 \%$ | $\geq 0 \%$ | $>20 \%$ |
| interval | ratios |  | ratios |  |
| 10 min. | 1.73 | 1.69 | 1.8 | 1.70 |
| 30 min. | 1.64 | 1.51 | 1.8 | 1.70 |
| 60 min. | 1.58 | 1.44 | 1.7 | 1.55 |

## 9. CONCLUSION

From a study of the distribution of signal levels for each frequency over a period of 10 days of recordings at St Remi, it was found that the transmissions from base-stations were constant to within $\pm 2 \mathrm{~dB}$ with respect to signal strength. This stability of base-station signals lends itself to the easy measurement of station occupancy; i.e., the fraction of the monitoring period during which the basestation is transmitting. Coyne (private communication), for simplex channels, has found that message occupancy which contains base-station occupancy, mobiles occupancy and intra-message gaps can be obtained by multiplying the base-station occupancy by a factor of about 3.2.

Two methods of representing the mean base-station occupancy have been defined. One method is the average taken over the number of days of monitoring and the other is the highest or maximum value of occupancy found on any day over the monitoring period. It has been shown that the uncertainty of these paraneters is a function of the number of days of monitoring, where 1 to 5 days have been considered and the values obtained from the 10 days of data have been assumed to represent the parent population. Corrections for the uncertainty have been calculated and are presented in Tables 2 and 3 respectively.

The above conclusions for the average and maximum method were based on the assumption that the occupancy remained fairly uniform throughout a day. From a study of the distribution of 5 -minate occupancies over 1 or more days, it was found that, in many cases, this assumption was not justified and that, for sharing purposes, a higher value of occupancy than the mean should be attributed to the current user. This new value of occupaney was derived from the $75 \%$ level of the cumulative distribution of the 5 -minute occupancies. On the average, this new value is 1.7 times the average value, i.e., a ratio of 1.7 . If the 5 -minute values are averaged to given I hourly values and the $75 \%$ level of the cumulative distribution of these 1 hourly values is used, the ratio reduces to 1.44 . The ratios given above are for those cases where the mean occupancy is $>20 \%$. If all cases are considered the ratio is slightly higher
but, since the ratio is required for sharing purposes and, with sharing, the occupancy will exceed $20 \%$ it is proposed that the lower values be used. The above average ratios should only be used for estimating the total spectrum available for sharing. In practice, for individual cases, the actual $75 \%$ level should be determined for each case.

If the sampling period is increased from 10 minutes to 30 minutes, the conclusions presented above with respect to the 5 minute occupancies remain unchanged. This is to be expected if the distribution is random. On the other hand, the 1 hourly average now contains only 2 samples for the average instead of 6 and the ratio is increased from 1.44 to 1.55 .

The data were also examined for diurnal variation, in particular, if there was a marked and systematic change in occupancy between the morning and afternoon periods. If so, it was considered that a new user with the opposite diurnal variation might be matched with a current user. However, only a few stations ( $8 \%$ ) were found to show a significant difference that might be utilized to save part of the spectrum and it was considered that this saving was not worthwhile in view of the limited number of channels available for this type of sharing. This conclusion was also based on the fact that many of these channels would be eliminated because of assignment restrictions (e.g. interference, allocation plan etc.) and because an estimate of the diurnal distribution of occupancy would be required of the new user (leading to the possibility of large errors).

In conclusion, while it is still premature to make any firm recomendations with respect to monitoring, it is suggested that monitoring be carried out from 3 to 5 days at a given site. However, the 5 -day scheme has much to recomend itself as it will cover those cases where a user might be particularly active on a given day of the week. Also, logistically the van can be moved to a new site over the weekend. In addition, a 5 -day scheme also allows for data loss due to equipment failure.

With respect to an occupancy parameter, it is suggested that both the average and maximum value be passed on to the end user, the district assignment officer. In addition, he should also be provided with the R75 ratio, both for the 10 -minute and the 60 -minute intervals. With experience, the best parameter should become apparent.

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