5 ANALYSIS AND RESULTS

This section discusses the various methods of statistical analysis employed to summarize the channel usage in various LMR bands. Graphs and tables summarizing the usage for the different bands are included in the latter half of this section, as well as in Appendix A.

5.1 Frequency Groupings

Two primary frequency groupings were analyzed as follows:

1. 162–174 MHz (excluding NOAA[11] weather radio channels located at 162.400, 162.425, 162.450, 162.475, 162.500, 162.525, and 162.550 MHz).
2. 406–420 MHz.

5.2 Channelization

As described in Section 2.1, channel assignments in these bands are now required to migrate toward a 12.5-kHz channelization; however, some LMR systems are still operating under the 25-kHz channelization scheme. To get an understanding of how much the newly created channels (spaced 12.5 kHz between the old assignments) are being used, analysis was performed on the following sets of channels:

1. all channels spaced 12.5 kHz apart.
2. channels assigned under the old 25-kHz channelization (spaced 25 kHz apart) – referred to in this report as "the old 25-kHz channels."
3. channels earmarked for the 12.5-kHz channelization (spaced 25 kHz apart and located halfway between the old 25-kHz channels) – referred to in this report as "the new 12.5-kHz channels."

5.3 Time Scenarios

Each of the 2 frequency groupings were analyzed according to 6 different time scenarios as follows:

1. **Entire week**: Data analyzed as a whole for the entire week Tuesday, October 26, 2004 at 2:00 PM through Wednesday, November 3, 2004 at 4:00 PM, independent of time or date.
2. **Date and time of day**: Data analyzed according to the date and time in one-hour blocks.

[11] National Oceanic and Atmospheric Administration.

3. **Time of day for any day**: Data analyzed according to time in one-hour blocks between 12:00 midnight and 12:00 midnight 24 hours later, independent of date or type of day (e.g., weekend day).
4. **Time of day for Election Day**: Data analyzed according to time in one-hour blocks between 12:00 midnight and 12:00 midnight 24 hours later only on Election Day (November 2).
5. **Time of day for weekdays**: Data analyzed according to time in one-hour blocks between 12:00 midnight and 12:00 midnight 24 hours later only for weekdays, independent of the type of weekday.
6. **Time of day for weekends**: Data analyzed according to time in one-hour blocks between 12:00 midnight and 12:00 midnight 24 hours later only for weekend days, independent of the type of weekend day.

5.4 High Occupancy Channels

In addition to the frequency and time groupings, data were also analyzed under two scenarios with regard to high occupancy channels (HOCs). HOCs, as defined for analysis under these measurements, are channels where the received signal level is above the detection threshold greater than 80% of the time (other than the NOAA weather radio channels, which were always excluded from analysis). Known examples of HOCs include channels used for telemetry (such as hydrology sensors) and control channels used in LMR trunked systems. Since these HOC channels differ greatly from the much lower percent usage of LMR channels, HOCs represent "outliers" that would substantially skew the mean LMR channel usage statistics. For this reason the data were sometimes processed with HOCs both included and excluded in the analysis, the latter providing a method for determining the usage for LMR channels that represent the overwhelming majority of signals in the LMR bands. These HOCs represent 1.1% of channels in the 162–174 MHz band, and 0.5% of channels in the 406–420 MHz band.

5.5 Busiest Hour Statistics

Several of the statistical summaries are reported for "busy hours," or a similar term, as applied to the usage of single channels or groups of channels. There are several distinct definitions for these processed statistics, which we will carefully describe here (as well as in sections 5.7) since substantially different numerical results can arise from slightly different processing algorithms.

The quantity that is loosely called "hourly usage" does not actually contain the results from 60 minutes of measurements. Instead, it represents the averaged results from whatever measurements were sampled during that hour. Typically, the hourly data were derived from two 4-minute measurement periods (separated by 32 minutes without measurements) for

frequencies in the 162–174 MHz band and from five 4-minute measurement periods (each separated by 8 minutes without measurements) for frequencies in the 406–420 MHz band. In about 12% of the hourly blocks in the 162–174 MHz band, the data were derived from a single 4-minute measurement. Sampling for less than the full hour can skew any of the "busy hour" results because a shorter sample period gives a greater statistical spread of percent usage for each channel. Typical usage in many of these channels tends to cluster into short periods of high activity, possibly with several almost-continuous exchanges between base and mobile stations, followed by a period of less usage. For a sample time shorter than a typical message, a given channel will tend to be used 100% of the time or not used at all. In a longer sample time, the short very-busy periods tend to be more smoothly averaged-out by the idle periods. Therefore, when looking at any of the busy-hour results, a shorter sample period tends to skew the data towards higher usage percentages.

In the following descriptions, we observe that the word "hour" has at least two distinct meanings: 1) a 60-minute period, and 2) a time of the day (e.g., "the hour is late"). In the "busy-hour" statistics, we will use "hour" only in the sense of an arbitrary 60-minute period, i.e., any hour of the day, week, or year. Whenever a specific time of the day is described, the term "time-of-day" will be used. Unless otherwise indicated, "time-of-day" will refer to the set of 24 one-hour time blocks that has been used to categorize the measurement data.

The *Hourly Channel Percent Occupancy* is computed for each channel, each hour of each day, by taking all of the *Channel Power Values* in an hour for a channel, comparing them to the detection threshold, and then determining the percent of values that exceed the threshold during that one-hour period.

The *Busiest Hour of the Week for Each Channel* is the specific 60-minute time block within the entire 1-week measurement period when the average usage on a given channel was highest. The *Busiest Hour of the Week for Each Channel* is determined by examining the *Hourly Channel Percent Occupancy* every hour of every day over the course of the measurements for each channel and identifying the "busiest hour" as the date and hour for the *Hourly Channel Percent Occupancy* with the largest value for each channel. Different channels will typically have a different date and time when the usage is highest.

The *Busiest Usage by Time-of-Day for Each Channel* is the highest average usage measured for a single channel during a particular time-of-day hourly block, over the course of the pertinent measurement period. There are 24 time-of-day hourly blocks, each lasting one hour and beginning and ending exactly on the hour. The *Busiest Usage by Time-of-Day for Each Channel* is computed by grouping into 24 separate time-of-day groups all of the *Hourly Channel Percent Occupancy* values within the pertinent measurement period (which could be a day or multiple days). The weighted average for each channel of all of the *Hourly Channel Percent Occupancy* values within each one-hour period is then determined. They are weighted because not all one-hour-periods have the same amount of acquired data. The highest of these 24 average values is called the *Busiest Usage by Hour for Each Channel*.

Figure 16 is a diagram of fictitious data used to represent the difference between these two different types of "busiest hour" statistics. This diagram shows the average usage for each hour of the day of a single channel, with each of the thin lines representing a different day during the course of the measurements. The green dot represents the *Busiest Hour of the Week for a Specific Channel* since it is the one hour out of all of the single-day plots for a specific channel that has the highest value. The thick black line represents an hourly average by time-of-day over the entire measurement period. The red dot represents the *Busiest Usage by Time-of-Day for a Specific Channel* since it is the largest value of the 24 time-of-day averages. One can say that, in this diagram, the *Busiest Hour of the Week for the Specific Channel* occurs at 6:00 AM on Day 1 and the *Busiest Usage by Time-of-Day for the Specific Channel* occurs at 3:00 PM.

The *Busiest Hour of the Week for Each Channel* method is used to determine the time of occurrence of the busiest hour for each channel (Figures 27 and 39), described later, which may help show whether "events" may cause high usage in multiple channels within the same hour. The *Busiest Usage by Time-of-Day for Each Channel* data is used to compile statistics showing how many channels were at various levels of usage during their busiest hour (e.g., Figures 34 and 46).

The *Average of Busiest Usage by Hour* is a single value that is computed by determining the average of all the usage values corresponding to the *Busiest Hour of the Week for Each Channel* across all channels in a band. These values are displayed in Tables A-1, A-2, A-5, and A-6 as "Busy Hour Usage (24 hours)."

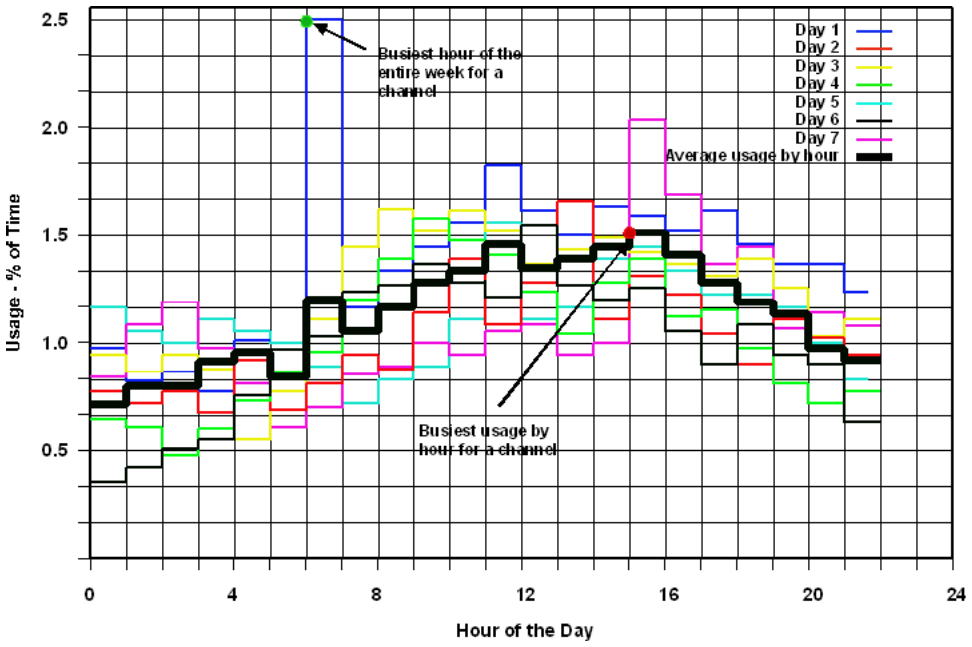


Figure 16. Diagram of fictitious data showing the difference between "busiest hour of the week" and "busiest usage by hour."

5.6 General Description of Analysis

The data is summarized with variations on 6 types of analysis:

(1) graphs of *Hourly Band Usage* during different 1-hour time periods.
(2) graphs of the *Busiest Hour of the Week for Each Channel.*
(3) APD graphs of *Channel Power Values* for all channels across the band.
(4) cumulative distribution graphs of the percent of channels (or hourly channel usage) exceeding a given percent usage.
(5) cumulative distribution graphs of the percent of channels that exceed a given percent of hours at greater than or equal to a given percent usage.
(6) tables of *Percent Band Usage* (during 24 hours and during the hours of 8:00 AM to 5:00 PM) and *Average of Busiest Usage by Hour* (during 24 hours).

Hourly Band Usage is determined by computing the *Hourly Channel Percent Occupancy* of each channel and then determining the mean usage of all the channels in the band. A graph of *Hourly Band Usage* is demonstrated in Figure 17, which shows both the *Hourly Band Usage* of channels in the band and total Erlangs (where Erlangs are determined by multiplying the *Hourly Percent Usage* by the total number of channels in the band – Table 6). Tic marks identify midnight. Each *Hourly Band Usage* represents a different hour and day.

Figure 18 shows *Band Occupancy by Time-of-Day*, which is determined by taking the *Hourly Band Usage* values for each hour of the day, and computing the average for the corresponding hours of the measurement period. Results in these example graphs are summarized for multiple mean threshold power levels (expressed in power at the antenna terminals and field strength at the input to the antenna), whereby a channel is considered to be occupied only if (as described in Section 4.3) the power exceeds the given threshold. As an example, Figure 18 shows that *Band Occupancy by Time-of-Day* of this sample data is approximately 2.8% at 10:00 AM when using a mean field-strength threshold of 12 dB μV/m. Variations of the *Hourly Band Usage* and *Band Occupancy by Time-of-Day* plots (summarized in Tables 7 and 8) consist of different frequency groupings, time scenarios, channelization schemes, and detection threshold levels.

While the *Band Occupancy by Time-of-Day* in Figure 18 varies between approximately 1-3%, readers are cautioned against drawing the conclusion that, because the channels in these bands were used 1-3% during the course of these measurements, 97-99% of the channels can be relinquished for other use. Because most of the channels in these bands are statically assigned to receivers, as opposed to dynamically assigned as is the case with trunked systems (see Definitions), many of these channels are reserved for high priority usage in which communication must be available at all times for a limited number of users, thus resulting in low percent usage. The Public Safety Wireless Advisory Committee (PSWAC) recommends in a report [9] that call-blockage (typically defined as Grade of Service) should not exceed “one call for service per one hundred attempts during the average busy hour.” That translates to no more than 1 percent usage for multi-user conventional (non-trunked) systems where channels are assigned statically.

It should also be noted that while the *Band Occupancy by Time-of-Day* in this band varies between approximately 1-3%, individual agencies may have averages that deviate from these values - either to a greater or lesser extent. Likewise, none of these measurements were made during a major emergency that might have greatly increased the use of radio channels.

Table 6. Total Number of Statistically Analyzed Channels Spaced 12.5 kHz Apart

Frequency Band	Number of Channels Analyzed
162–174 MHz – including HOCs	944
162–174 MHz – excluding HOCs	934
406–420 MHz – including HOCs	1119
406–420 MHz – excluding HOCs	1113

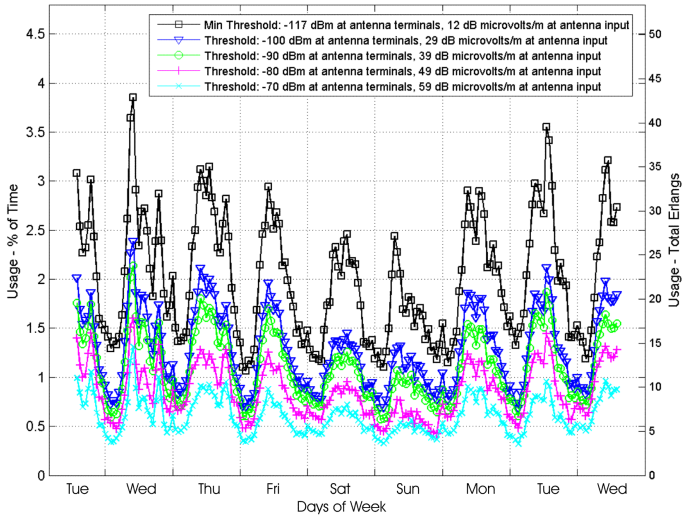


Figure 17. Sample graph (reference to Figure A-2) of *Hourly Band Usage* (percent of time and total Erlangs).

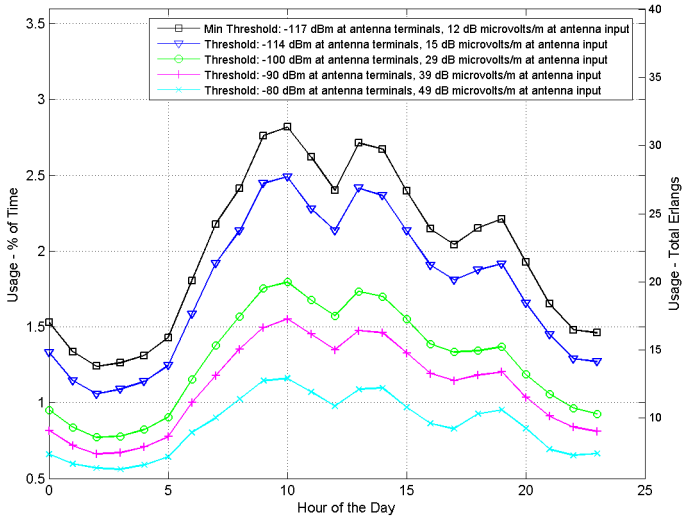


Figure 18. Sample graph (reference to Figure 42) of *Band Occupancy by Time-of-Day* (percent of time and total Erlangs).

As previously explained in Section 4.3, the detection threshold values in these figures are mean threshold values, where the average is determined across the appropriate range of frequencies.

An example of the *Busiest Hour of the Week for Each Channel* is displayed in the graph in Figure 19. The x-axis is divided into one-hour blocks throughout the week and the y-axis represents the individual channel frequencies. One-hour time slots in which anomalies occurred (as described in the latter part of this section) were excluded from processing. The purpose of this type of graph is to display the distribution of channel usage throughout the passage of time to identify possible aggregation of channel usage at certain time blocks. For instance, there are diurnal patterns where the use is heaviest at certain hours of the day, and during those heaviest-use times, certain groups of adjacent channels were simultaneously busy. For instance, multiple channels between 173–174 MHz had the heaviest usage at approximately 3:00 AM on Saturday morning (point A). It should be kept in mind, however, that whenever large numbers of adjacent frequencies appear to become busy at the same time, there is a possibility that the measurements were being affected by broadband RF energy, radiated intentionally or accidentally. Also note that data on different groups of frequency channels (3 groups for each of the two bands) were acquired at different blocks of time. Therefore, correlation between these different blocks may not exist since the heavy use may have occurred during the acquisition of one frequency group but not the others. Correlation within the frequency groups of simultaneously acquired data could exist if a significant event triggered multiple use of channels in that group.

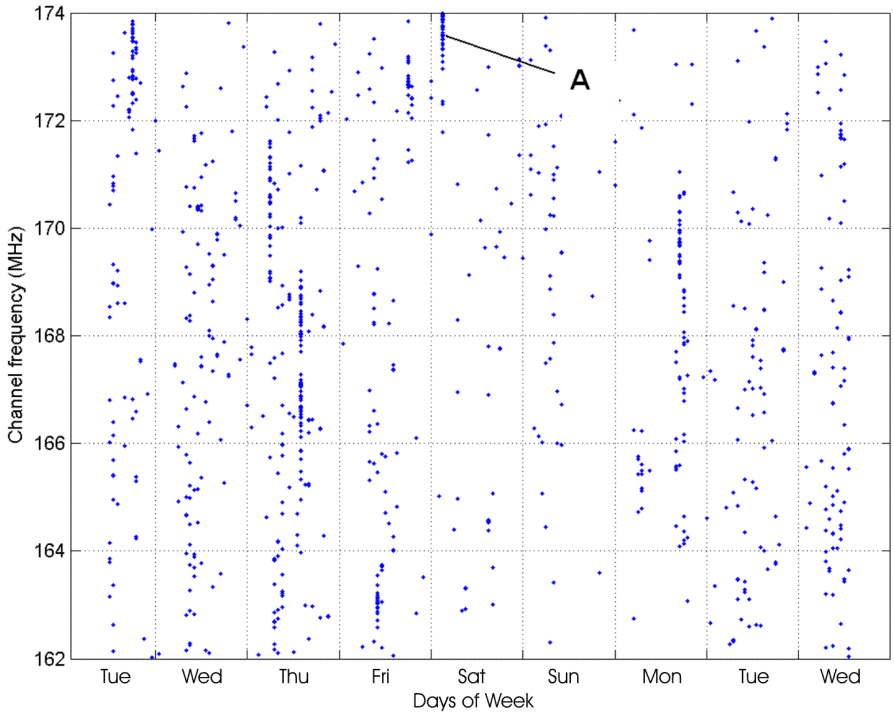


Figure 19. Sample graph (reference to Figure 27) of the *Busiest Hour of the Week for Each Channel*.

APD graphs of *Channel Power Values* are cumulative probability distribution plots representing the percent probability of a channel exceeding a given *Channel Power Value* at any one moment, where the y-axis displays power and the x-axis displays the probability expressed on a Rayleigh scale. A detailed description of APDs is provided in a tutorial located in Appendix A of [1].

Figure 20 shows an APD plot of *Channel Power Values* for all channels in a band. There are two lines on the plot, one that shows the percent probability of a channel exceeding a given *Channel Power Value* and the other showing the percent probability of exceeding a given power due only to Gaussian system noise (represented by the slightly sloped horizontal line). Points on the first line that deviate from the latter line are due to either LMR signals and/or RF noise that exceeds the system noise. Because most of the impulsive noise was removed using the techniques described in Section 4.1, points deviating from the system noise curve are believed to be due primarily to LMR signals. The y-axis is displayed in both *Channel Power Value* at the antenna terminals in dBm and field strength in dB μV/m. For example, Figure 20 shows that there is a 1 percent chance that the *Channel Power Values*

for the channels in the band exceed a field strength of 44 dB μV/m at the measurement antenna input or -85 dBm at the antenna output.

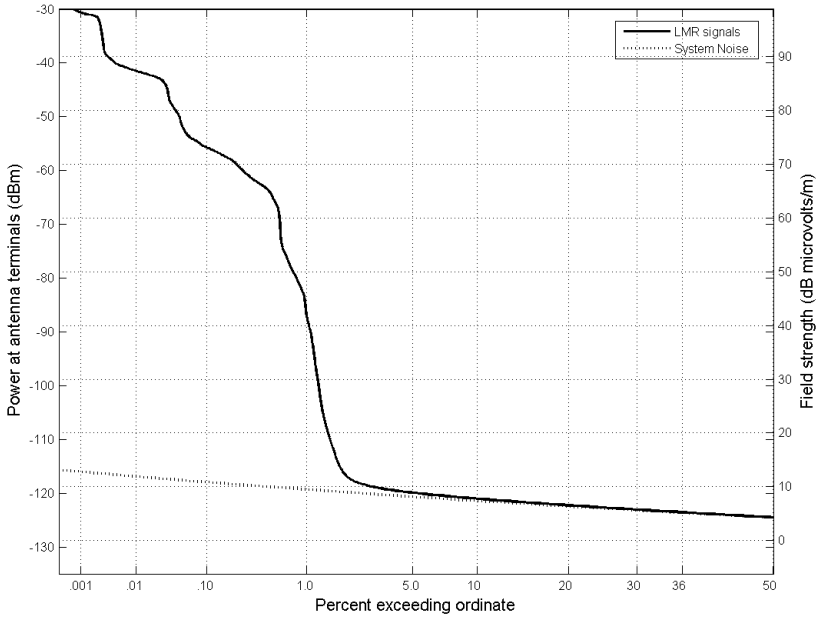


Figure 20. Sample APD (reference to Figure 47) of *Channel Power Values* for all channels in a given band.

Figure 21 shows a representative cumulative distribution graph of *Hourly Channel Percent Occupancy* values that exceed a given percent usage for different channelization and HOC scenarios, whereby a channel is considered to be "occupied" whenever (as described in Section 4.3) the measured power exceeds a given detection threshold (-113 dBm, in this example). In this figure, for the case of all channels spaced 12.5 kHz apart with the HOCs excluded, it can be seen that 13 percent of the *Hourly Channel Percent Occupancy Values* have a percent usage of greater than 1 percent, or conversely that 87 percent of all 12.5-kHz channels have a usage less than 1 percent. Similar conclusions can be determined for the other channelization cases presented in Figure 21. Note that a channel was considered to be an HOC when the measurements showed an 80 percent or more mean usage over the 8-day measurement period. However, it is possible for a channel with mean weekly usage of less than 80 percent to have some hourly periods where that value is exceeded. Those periods are still included in these statistics.

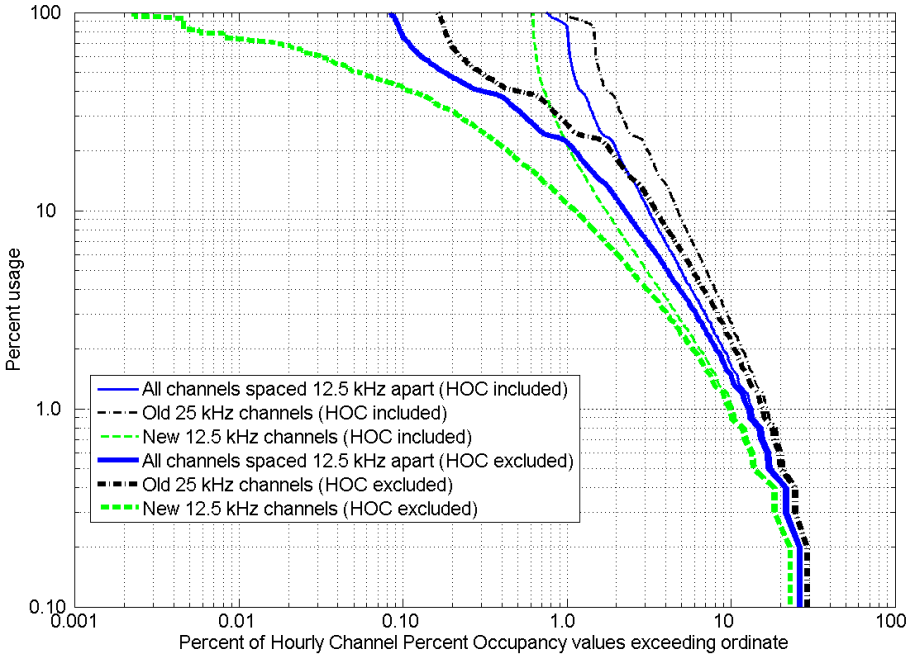


Figure 21. Sample graph (reference to Figure 32) of the percent of *Hourly Channel Percent Occupancy* values exceeding a given percent usage.

Figure 22 shows the *Channel Percent Occupancy* for the week of measurements. This is computed for each channel by taking every *Channel Power Value* for each 1-second acquisition every day and comparing that to the detection threshold to determine an overall percent occupancy for the specific channel. As shown in Figure 22, for the case of all channels spaced 12.5 Hz apart with HOC excluded, 15 percent of the *Channel Percent Occupancy* values have a mean percent-usage of greater than or equal to 1%, or conversely, that 85 percent of the *Channel Percent Occupancy* values have a usage less than 1%. Similar conclusions can be determined for the other channelization cases presented in Figure 22. For this figure, note that typical measured hourly usage values for a given channel may vary greatly, with occasional hourly periods of unusually high or low usage. The effect of averaging the hourly usage values into a weekly channel usage value causes the weekly values to have much less variability than the corresponding hourly values. This effect is clearly shown by comparing the case of all channels spaced 12.5 kHz apart (HOC excluded) in Figures 21 and 22.

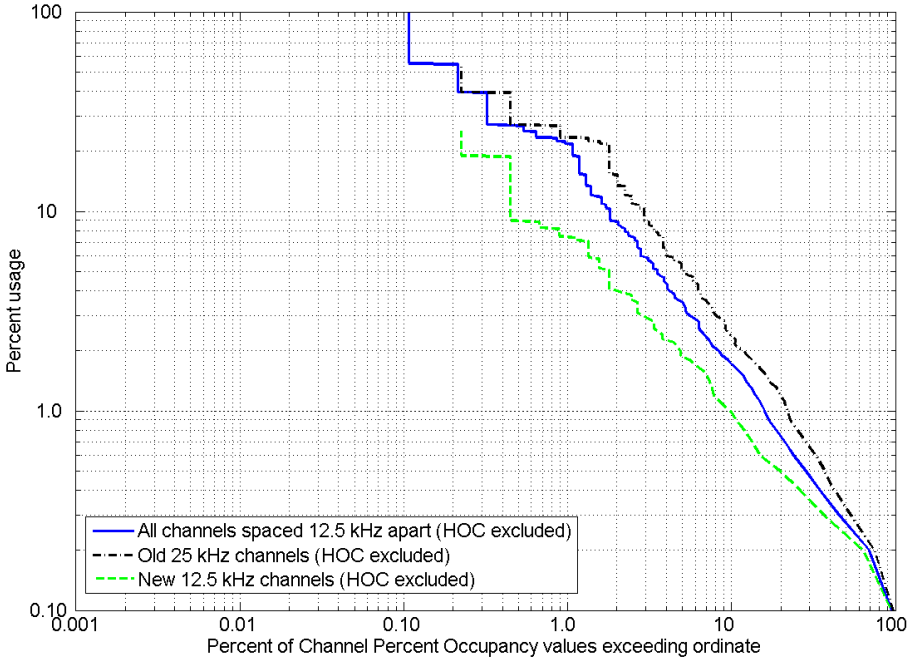


Figure 22. Sample graph (reference to Figure 33) of the percent channels exceeding a given percent usage for *Channel Percent Occupancy*.

The cumulative distribution of usage is also presented in one final form. Figure 23 shows the percent of channels exceeding a given percent usage for the *Busiest Usage by Time-of-Day for Each Channel*. In this figure, for the case of all channels spaced 12.5 kHz apart with HOC excluded (weekdays only), 60 percent of the channels have a *Busiest Usage by Time-of-Day* greater than 1%, 10 percent of the channels have a usage greater than 7 percent and 1 percent of the channels have a usage greater than 34%.

Much of the data presented in this report is represented in the form of "mean usage" which is meant to convey "typical" usage by a channel. However, because the percent usage statistics are not Gaussian distributed, and because, as shown in Figure 23, there are a few channels with relatively high usage (20 percent of the channels with greater than 2 percent usage) but there are far more channels with relatively low usage (80 percent with less than 2 percent usage) the mean is skewed, due to outliers, towards a larger value than what one might think of as "typical." This is because the overwhelming majority of usage value are around 1-3% but there are individual values much greater than this that tend to computationally bias the mean to a higher value. In this case, the median may be more representative of what is a "typical" channel usage – depending upon how the statistic is used. This median value can be easily determined by looking at the 50% point along the x-axis of the cumulative distribution graphs and finding the corresponding percent-usage on the usage plot. In Figure 23, as an example, the median of *Busiest Usage by Time-of-Day* is 1.3 percent.

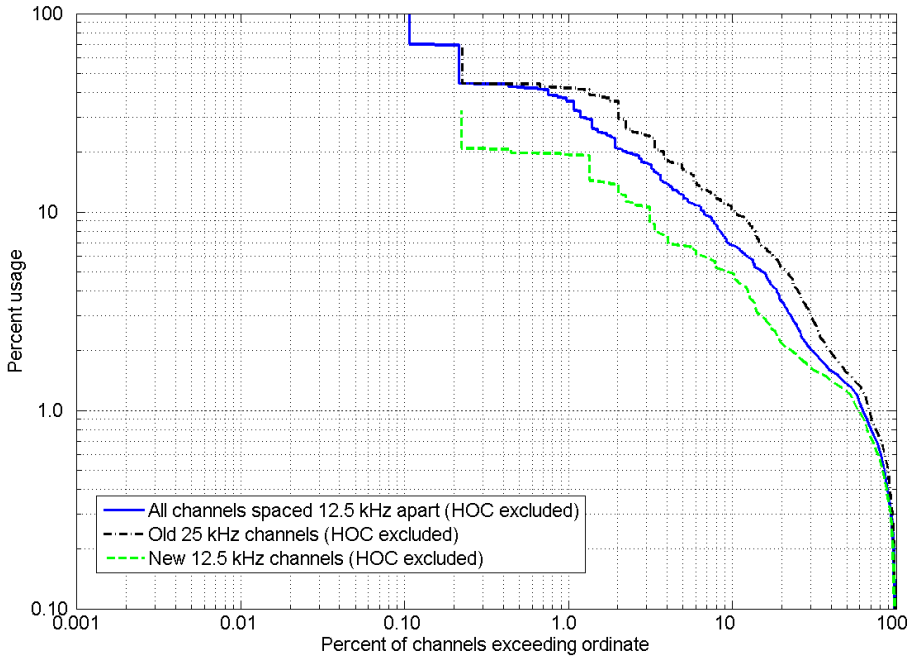


Figure 23. Sample graph (reference to Figure 34) for percent of channels exceeding a given percent usage for the *Busiest Usage by Time-of-Day* during weekdays only.

Note that Figures 21 and 22 are based on the entire week of measurements, while Figure 23 is based on weekday measurements only. This was done because the busiest hours occurred during the weekdays.

Figure 24 shows a representative cumulative distribution graph of the percent of channels that exceed a given percent time at greater than or equal to a given usage for the entire 8-day period of the measurements, where time is broken into 1-hour segments for which average usage is determined. In this case, usage refers to *Hourly Channel Percent Occupancy* as defined in Section 5.5. Each hour time-slot represents an average of 6.7 minutes of data acquisition in the 162-174 MHz band and 15 minutes of data acquisition for the 406-420 MHz band. Each line in the graph represents a unique percent-usage (*Hourly Channel Percent Occupancy*) as noted in the graph legend. For example, consider the case of the line that represents the percent usage of 1 percent. Point A (annotated on the 1 percent usage line) shows that for this case, approximately 33 percent of the channels have 10 percent or more of the 1-hour periods in which the usage is 1.0 percent or greater. Conversely, 67 percent of the channels have less than 10 percent of the 1-hour periods in which the usage is 1.0 percent or greater. Or 67 percent of the channels have 90 percent or more of the 1-hour periods in which the usage is less than 1.0 percent. Another example is the case of the line that represents the usage being 5 percent. Point B (annotated on the 5 percent usage line) shows that for this case, approximately 20 percent of the channels have 3 percent or more of the 1-hour periods in which the usage is 5.0 percent or greater. Conversely, 80 percent of the channels have less than 3 percent of the 1-hour periods in which the usage is 5.0 percent or greater. Or 80 percent of the channels have 97 percent or more of the 1-hour periods in which the usage is less than 5.0 percent. Note that discrete steps occur in the "percent of hourly periods" lines because there are a discrete number of one-hour time slots over the course of the measurement. Since there were approximately 196 hours of measurement during the course of the 8 days, a single one-hour time slot represents a "percent of hourly periods" of 0.51%, two hours is 1%, and three hours represents 1.5% (consistent with the discrete steps seen in Figure 24).

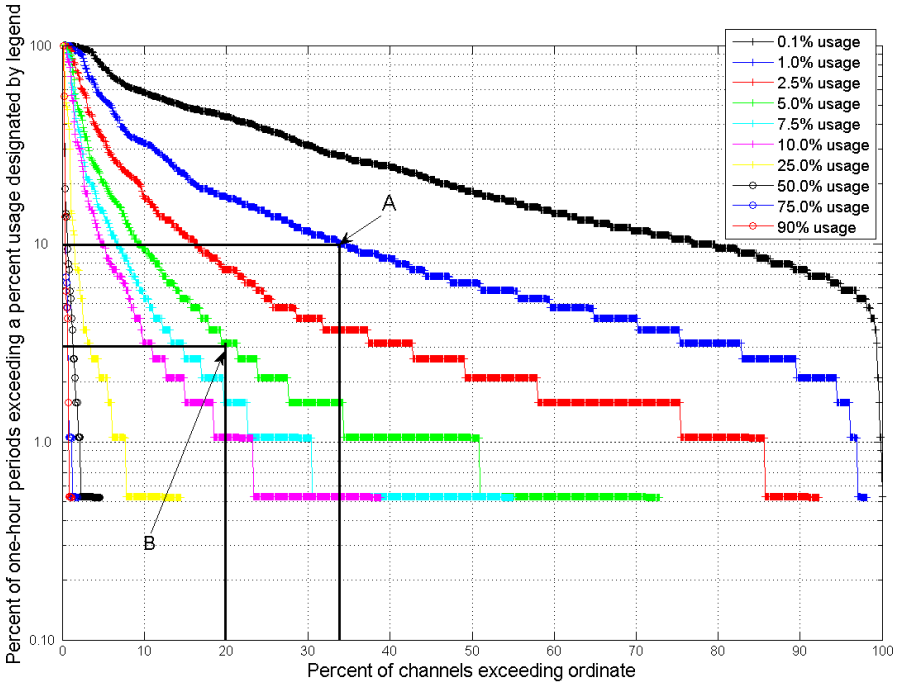


Figure 24. Sample (reference to Figure 37) cumulative distribution graphs of the percent of channels that exceed a given percent of hours at greater than or equal to a given usage (*Hourly Channel Percent Occupancy)*.

Table 7 is a representative table showing *Percent Band Usage* and *Average of Busiest Usage by Hour* expressed in percent usage. *Percent Band Usage* is determined by computing the mean of all *Hourly Channel Percent Occupancy* values for all channels during the measurement period. *Average of Busiest Usage by Hour* is defined in Section 5.5. The table shows *Percent Band Usage* over a 24-hour period, as well as between 8 AM to 5 PM, and *Average of Busiest Usage by Hour* over a 24-hour period. The associated values are given for 5 different detection threshold levels represented both by power in dBm at the antenna terminal for the particular antenna and field strength in dB µV/m at the antenna input. Ninety-nine percent confidence intervals, the derivation of which is described in Appendix A, are given for percent usage values determined at the minimum detection threshold. The mean usage values for *Average of Busiest Usage by Hour* are only reported for the minimum detection threshold, since the minimum threshold is used to determine which hour of the day is the busiest. It is not valid to use other thresholds to calculate the

Average of Busiest Usage by Hour. Variations of Table 7 (provided in Appendix A) consist of different frequency groupings and time scenarios.

Table 7. Sample Table Showing Mean Percent Usage and Mean Erlangs for 934 Channels (Reference to Table A-1)

All Days	**Mean Detection threshold**				
Threshold (dBm)	-113	-100	-90	-80	-70
Threshold (dBμV/m)	8	21	31	41	51
Timescale	**Percent Band Usage**				
Percent Band Usage (24 hours)	1.08±0.01[12]	0.63	0.5	0.27	0.21
Average of Busiest Usage by Hour	2.72±0.08[12]	Not applicable			
Percent Band Usage (8am–5pm)	1.42±0.02[12]	0.76	0.6	0.37	0.3
Note: Mean Erlangs can be calculated by multiplying the Percent Band Usage for any threshold by the number of channels. For example, Mean Erlangs for a threshold of -113 dBm is 10.95 (1.08 * 934).					

The relationship between the cumulation distributions (Figures 21 and 22) and the values in Table 7 can be understood better by considering how Figure 21 can be crudely analyzed to give the data shown in Table 7. Figure 25 shows the principles of this analysis, using the corresponding data in each figure. The solid black line in Figure 25 (all channels spaced 12.5 kHz apart, HOC excluded) corresponds to the "1.08" mean percent usage in Table 7 (-113 dBm threshold, 24 hours per day usage). Figure 25 illustrates the process of converting Figure 21 data into an entry in Table 7.

The area under the solid black cumulative distribution line in Figure 25 (see arrow) can be approximated by a series of rectangular areas. The leftmost of these areas represents the point on the line that says .09% of all channels have a usage of approximately 100%. The general approach will be to see what proportion of channels have what values of usage, to give a total percent usage for the entire band. The following table summarizes the values used in the rectangular approximations.

[12]99% confidence level – assuming an **average** message length of no greater than 5 seconds.

The derived answer of 1.007% compares to the answer in Table 7 of 1.08%, which is a reasonable accuracy considering the approximations used.

Table 8. Summary of values used in the rectangular approximations of mean percent usage

Percent of channels			Mean usage	Total usage
min	m ax	net	(% usage)	(channels x usage)
0	0.09	0.09	100%	1.000 x 0.09% = 0.090%
0.09	0.2	0.11	60%	0.600 x 0.11% = 0.066%
0.2	0.5	0.3	40%	0.400 x 0.30% = 0.120%
0.5	1	0.5	25%	0.250 x 0.50% = 0.125%
1	2	1	16%	0.150 x 1.00% = 0.150%
2	5	3	7%	0.070 x 3.00% = 0.210%
5	10	5	3%	0.030 x 5.00% = 0.150%
10	22	12	0.8%	0.008 x 12.0% = 0.096%
				Total usage = 1.007%

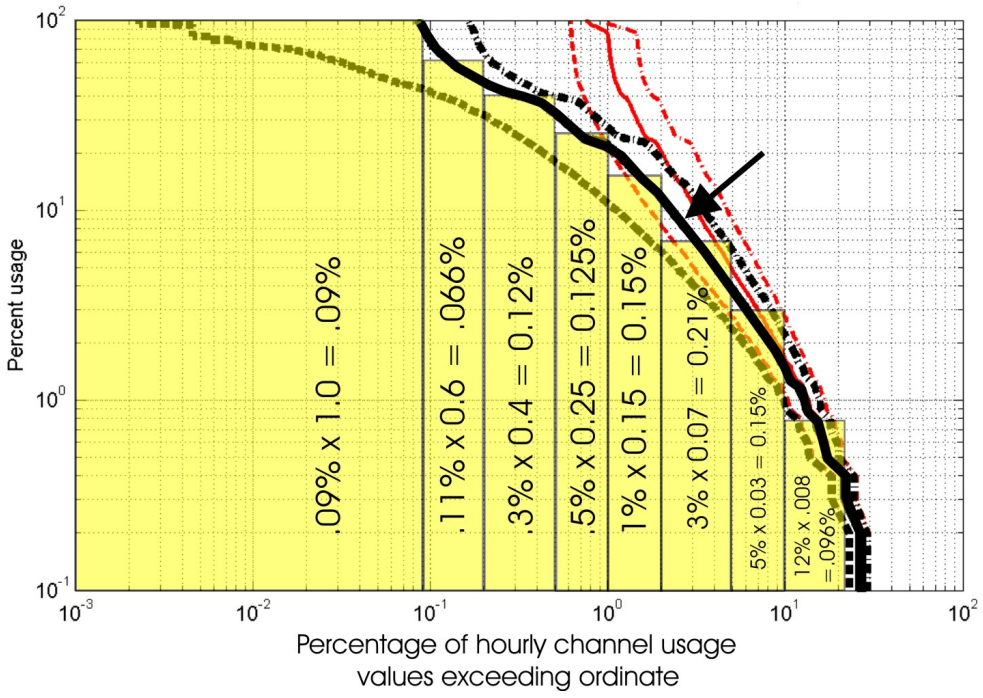
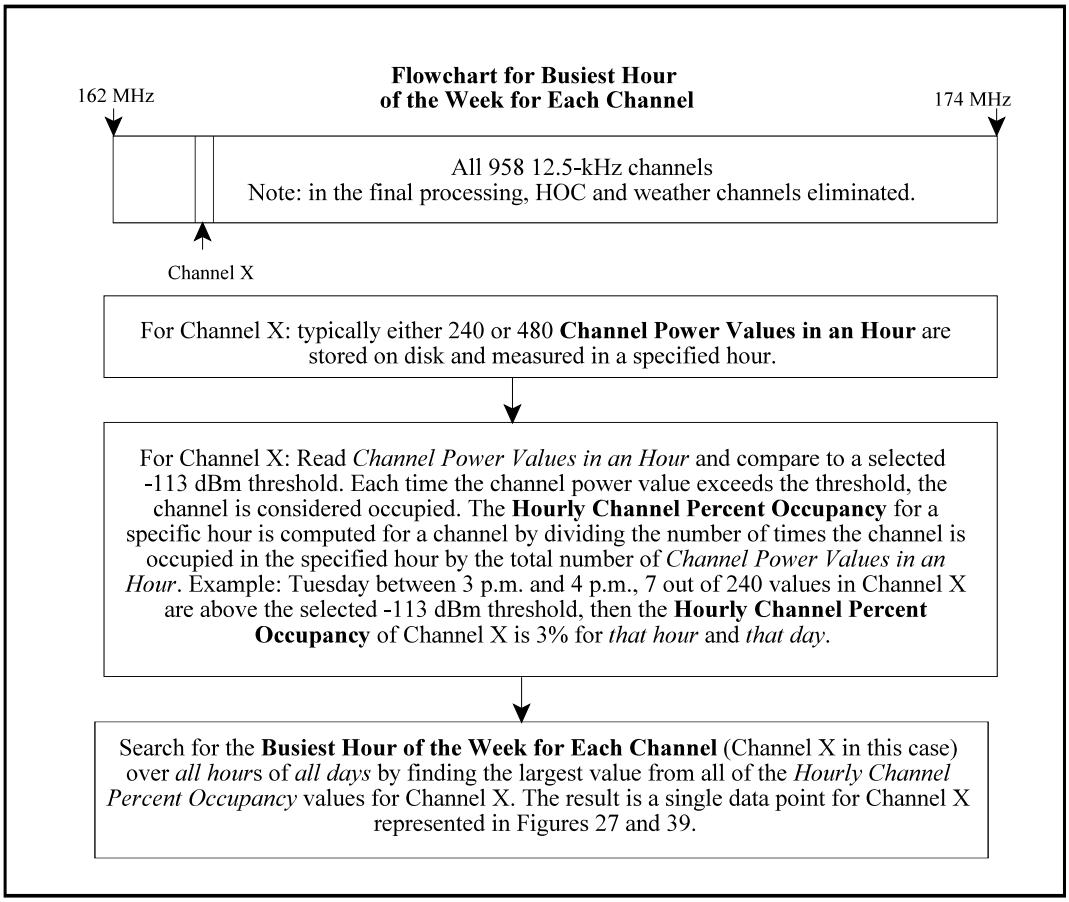


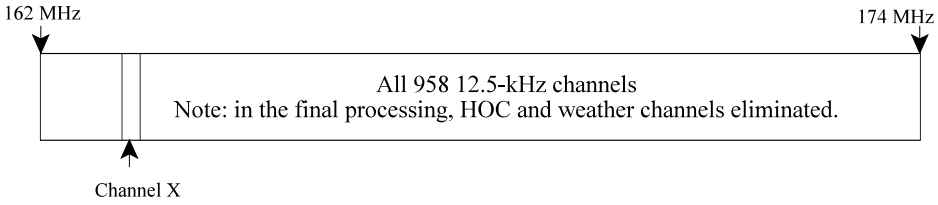
Figure 25. Calculating mean hourly channel usage.

5.7 Summary of Processing

The flowcharts in this section summarize the process that was used for obtaining the following statistics: *Busiest Hour of the Week for Each Channel, Busiest Usage by Time-of-Day for Each Channel*, *Average of Busiest Usage by Hour*, *Band Occupancy by Time-of-Day*, and *Maximum Band Occupancy*.



Flowchart for Busiest Usage by Time-of-Day and Average of Busiest Usage by Hour



For Channel X: typically either 240 or 480 **Channel Power Values in an Hour** are stored on disk and measured in a specified hour.

For Channel X: Read *Channel Power Values in an Hour* and compare to a selected -113 dBm threshold. Each time the channel power value exceeds the threshold, the channel is considered occupied. The **Hourly Channel Percent Occupancy** for a specific hour is computed for a channel by dividing the number of times the channel is occupied in the specified hour by the total number of *Channel Power Values in an Hour*. Example: Tuesday between 3 p.m. and 4 p.m., 7 out of 240 values in Channel X are above the selected -113 dBm threshold, then the **Hourly Channel Percent Occupancy** of Channel X is 3% for *that hour* and *that day*.

Compute **Usage by Time-of-Day for Each Channel** during the entire week by summing the weighted *Hourly Channel Percent Occupancy* for a given hour using the minimum threshold. **Usage by Time-of-Day for Each Channel** is given by

$$u_{ij} = \frac{\sum_{k=1}^{D} c_{ijk} w_{jk}}{D},$$

where u_{ij} is the **Usage by Time-of-Day for Each Channel** for the i^{th} channel and the j^{th} hour of the day, c_{ikj} is the *Hourly Channel Percent Occupancy* for the i^{th} channel, the k^{th} day of the measurement, and the j^{th} hour of the day, w_{kj} is the weight factor for the the k^{th} day of the measurement and the j^{th} hour, and D is the number of days during the course of the measurement. The respective hourly values are weighted proportional to the number of measurements used in computing the hourly values since not all *Hourly Channel Percent Occupancy* values contain data based on an equal number of measurements.

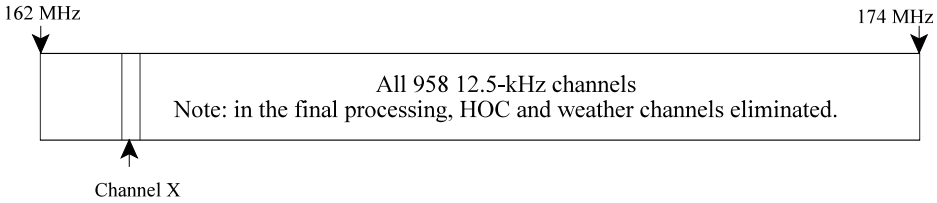
Determine the **Busiest Usage by Time-of-Day for Each Channel** by finding, for each channel, the *Usage by Time-of-Day for Each Channel* value that is the largest out of the 24 values. There is only one *Busiest Usage by Time-of-Day* value for each channel.

Compute the **Average of Busiest Usage by Hour** by averaging, across all channels, the values for *Busiest Usage by Time-of-Day for Each Channel.* Example: Channel 1, Hour 4, 1.2%; Channel 2, Hour 2, 18.6%; ....Channel 958, Hour 24, 5.3%. **Average of Busiest Usage by Hour** (p) is given by

$$p = \frac{\left(\sum_{i=1}^{N} b_i \right)}{N},$$

where b_i is the *Busiest Usage by Time-of-Day* for the ith channel, and N is the number of channels. The result is a single data value for the entire band, displayed in Tables A-1, A-2, A-5, and A-6 as the "Average of Busiest Hour."

Flowchart for Band Occupancy by Time of Day and Maximum Band Occupancy



For Channel X: typically either 240 or 480 **Channel Power Values in an Hour** are stored on disk and measured in a specified hour.

For Channel X: Read *Channel Power Values in an Hour* and compare to a selected -113 dBm threshold. Each time the channel power value exceeds the threshold, the channel is considered occupied. The **Hourly Channel Percent Occupancy** for a specific hour is computed for a channel by dividing the number of times the channel is occupied in the specified hour by the total number of *Channel Power Values in an Hour*. Example: Tuesday between 3 p.m. and 4 p.m., 7 out of 240 values in Channel X are above the selected -113 dBm threshold, then the **Hourly Channel Percent Occupancy** of Channel X is 3% for *that hour* and *that day*.

Compute the **Hourly Band Usage** by taking all of the *Hourly Channel Percent Occupancy* values in a given hour of a given day and averaging across all of the channels in the band. **Hourly Band Usage** (h_{jk}) for the j^{th} hour of the k^{th} day is given by

$$h_{jk} = \left(\sum_{i=1}^{N} c_{ijk} \right) \Big/ N ,$$

where c_{ijk} is the *Hourly Channel Percent Occupancy* for the i^{th} channel, the k^{th} day of the measurement, and the j^{th} hour of the day, and N is the number of channels. The result of this processing is displayed in Figures 26, 28, 38, 40, 50, 52, A-1, and A-2.

Compute the **Band Occupancy by Time-of-Day** by taking the *Hourly Band Usage* values for each hour of the day and averaging together the values for corresponding hours of the day across all days of the measurement. **Band Occupancy by Time-of-Day** (d_j) for the j^{th} hour of the day is given by

$$d_j = \left(\sum_{k=1}^{M} h_{jk} \right) \Big/ M ,$$

where h_{jk} is the *Hourly Band Usage* for the k^{th} day of the measurement, and the j^{th} hour of the day, and M is the number of days during the measurement. The result of this processing is displayed in Figures 29, 30, 31, 41, 42, and 43.

The ***Maximum Band Occupancy*** is the maximum of all the ***Band Occupancy by Time-of-Day*** values for a day. It is represented by a single data point on Figure 30 (as annotated).

5.8 Measurement Results

Figures 26 through 49 summarize results using the various graphs described in the previous section. As a quick reference, Tables 9 and 10 provide figure numbers for various plot types. For statistics that do not provide results for multiple threshold levels, only the minimum threshold is used, the values of which are listed in Table 11.

Table 9. Figure Numbers for Graphs in the 162–174 MHz Band

Hourly Band Usage	X		X										X
Busiest Hour of the Week for Each Channel		X											
Band Occupancy by Time-of-Day				X	X	X							
% Hourly Channel Percent Occupancy Values Exceeding % Usage							X						
% Channels Exceeding % Usage for Channel Percent Occupancy								X					
% Channels Exceeding % Usage for Busiest Usage by Time-of-Day for Each Channel									X				
APD of Channel Power Values										X	X		
% Channels Exceeding a Given % of Hours at Greater than or Equal to a Given % Usage												X	
Multiple Thresholds						X							X
Mult Channelization Scenarios	X		X		X		X	X	X	X			
Multiple HOC Scenarios							X				X		
Multiple Time Scenarios				X									
Including HOC		X	X				X				X		
Excluding HOC	X			X	X	X	X	X	X	X	X	X	X
Entire Week							X	X	X	X	X	X	
Date and Time of Day	X	X	X										X
Time for Any Day				X	X	X							
Election Day				X									
Weekdays				X									
Weekend Days				X									
All Channels	X	X	X	X	X	X	X	X	X	X	X	X	X
25-kHz Channelization	X		X		X		X	X	X	X			
12.5-kHz Channelization	X		X		X		X	X	X	X			
Figure Number	26	27	28	29	30	31	32	33	34	35	36	37	A-1

Table 10. Figure Numbers for Graphs in the 406–420 MHz Band

Hourly Band Usage	X		X										X
Busiest Hour of the Week for Each Channel		X											
Band Occupancy by Time-of-Day				X	X	X							
% Hourly Channel Percent Occupancy Values Exceeding % Usage							X						
% Channels Exceeding % Usage for Channel Percent Occupancy								X					
% Channels Exceeding % Usage for Busiest Usage by Time-of-Day for Each Channel									X				
APD of Channel Power Values										X	X		
% Channels Exceeding a Given % of Hours at Greater than or Equal to a Given % Usage												X	
Multiple Thresholds						X							X
Mult Channelization Scenarios	X		X		X		X	X	X	X			
Multiple HOC Scenarios							X				X		
Multiple Time Scenarios				X									
Including HOC		X	X				X				X		
Excluding HOC	X			X	X	X	X	X	X	X	X	X	X
Entire Week							X	X	X	X	X	X	
Date and Time of Day	X	X	X										X
Time for Any Day				X	X	X							
Election Day				X									
Weekdays				X									
Weekend Days				X									
All Channels	X	X	X	X	X	X	X	X	X	X	X	X	X
25-kHz Channelization	X		X		X		X	X	X	X			
12.5-kHz Channelization	X		X		X		X	X	X	X			
Figure Number	38	39	40	41	42	43	44	45	46	47	48	49	A-2

Table 11. Minimum Detection Threshold Values

Frequency Band	dBm at antenna terminals	dB μV/m field strength
162–174 MHz	-113	8
406–420 MHz	-117	12

Several of the channel-usage graphs show anomalies that require further explanation (anomaly, meaning data that does not reflect what is truly happening). As can be seen in Figure A-1 in Appendix A, as well as Figures 26 and 28, there are three different times (at the beginning, midway, and at the end of the week) in which all of the usage values go to zero. The reason for this is that, during this time, no data were collected in the bands of interest, and therefore usage erroneously appears to be zero. This anomaly occurs only in the 162–174 MHz band. Another anomaly that occurs – but only in the 162–174 MHz band (as seen in Figures A-1, 26, and 28) – can be seen at approximately 10:00 AM on Thursday, in which usage values for all data plots exceed 2.5 percent usage. Upon examining the usage data in greater detail it was determined that this was due to an incomplete data set where the data collected was in a small section of the spectrum that had greater usage than the average. A third anomaly occurs at midday on Sunday and Monday in which only the data for the minimum detection threshold exceed 2.5 percent usage. This occurs in the 162–174 MHz band and can be seen in Figures A-1, 26, and 28. Examining the usage data in greater detail revealed periods of increased noise that were high enough to raise the statistics for mean usage on the minimum detection threshold plot but were not high enough to be detected and removed by the processing techniques described in Section 4.1. This phenomenon also has an impact on the 24-hour plot shown in Figure 31, in which only the minimum detection threshold plot appear to have this anomaly. For APD plots, time periods during which this aberrant noise condition occurred were excluded from analysis. To improve readability of the week-long plots, the latter anomalies are often cut off by the top of the graphs, since this data is not relevant to the usage analysis. As shown in Figure A-2 of Appendix A, none of the anomalies occurred in the 406–420 MHz band.

To give some indication of the degree to which assignments have migrated to the 12.5-kHz channel spacing, several of the graphs show statistical summaries for 3 different channelization schemes as described in section 2.1. These include the following:

1. all channels spaced 12.5 kHz apart.
2. the old 25-kHz channels (spaced 25 kHz apart).
3. the new 12.5-kHz channels (spaced 25 kHz apart and located halfway between the old 25-kHz channels).

Statistics for each of the three categories are determined only for the channel frequencies indicated. However, because ACPR requirements, as specified in Section 2.2, require 25-kHz channels only to be attenuated in the adjacent 25-kHz channel, there is likely to be significant

signal power in the adjacent channel spaced 12.5 kHz away. Therefore, some of the new 12.5-kHz channels are likely to show usage even though the power simply comes from an adjacent old 25-kHz channel. From the standpoint of percent-usage of all channels spaced 12.5 kHz apart, a channel 12.5 kHz away from the center frequency of a wider bandwidth transmission in an old 25-kHz channel is considered to be occupied, even though the power comes from an adjacent channel; however, because the two adjacent channels 12.5 kHz away from the center frequency of the wider bandwidth transmission will show less power, the mean for percent usage of all channels spaced 12.5 kHz apart is likely to be slightly low since their values may, at times, fall below the threshold. On the other hand, statistics for usage of the new 12.5-kHz channels are likely to show mean-usage values slightly higher than the true value because the channel is not being used for a transmission as a new 12.5-kHz channel but is simply showing usage because there is sideband power in the channel from an adjacent old 25-kHz channel.

5.8.1 Results for 162–174 MHz Band

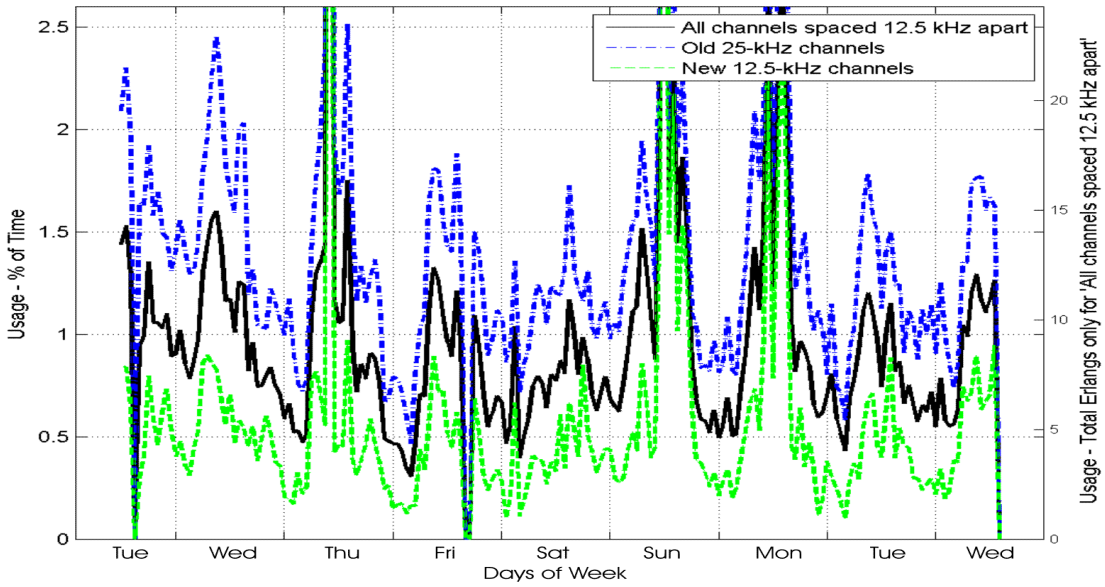


Figure 26. *Hourly Band Usage* (percent of time and total Erlangs) during the course of the measurements for the 162–174 MHz band (excluding HOCs; minimum thresholds).

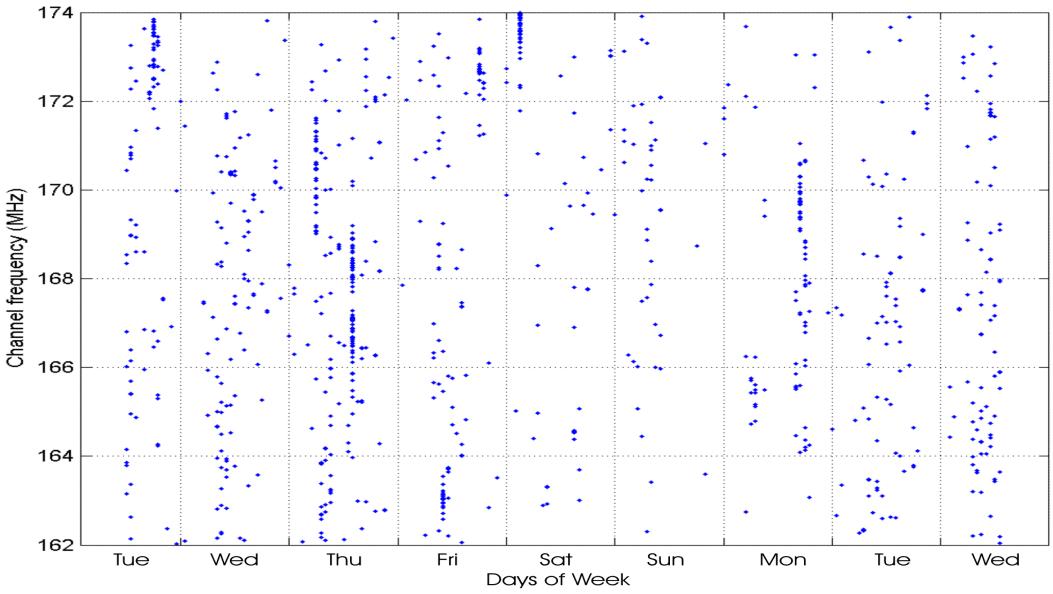


Figure 27. *Busiest Hour of the Week for Each Channel* in the 162–174 MHz band.

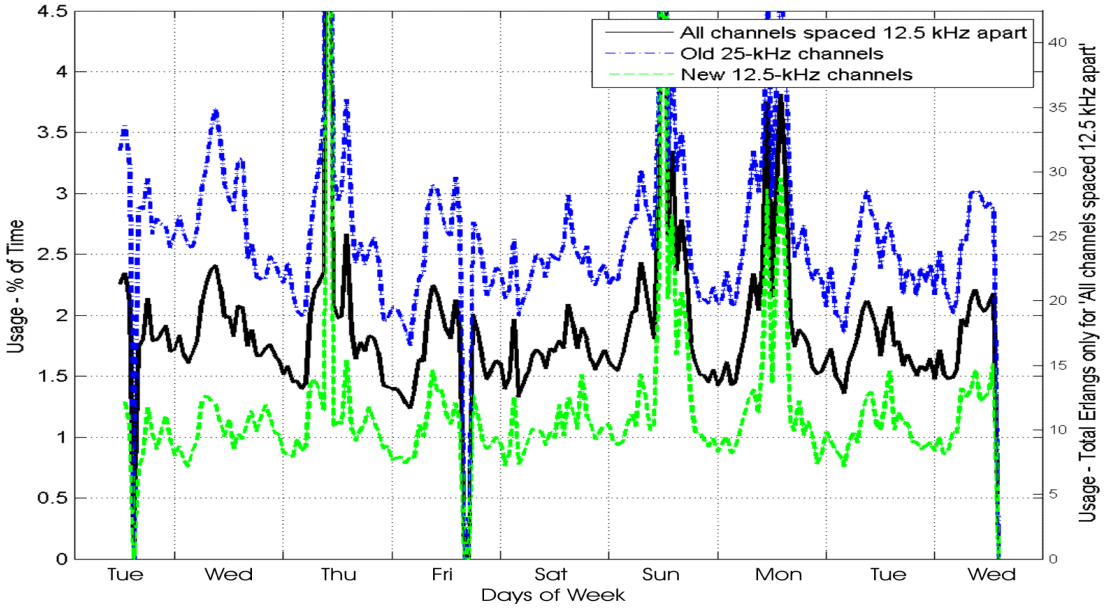


Figure 28. *Hourly Band Usage* (percent of time and total Erlangs) during the course of the measurements for the 162–174 MHz band (including HOCs; minimum threshold).[13]

[13] As previously noted, both Figures 26 and 28 have some anomalies that require explanation. There are three different times (at the beginning, midway, and at the end of the week) in which all of the plot values go to zero. The reason for this is that, during this time, no data were collected in the bands of interest, and therefore usage erroneously appears to be zero. Another anomaly can be seen at approximately 10:00 AM on Thursday, in which all data plots exceed 4 percent usage. Upon examining the data in greater detail it was determined that this was due to an incomplete data set in which the data collected was a small section of the spectrum that had greater usage than the average. A third anomaly occurs at midday on Sunday and Monday in which only the data for the minimum threshold exceed 2.5 percent usage. Examining this data in greater detail revealed periods of increased noise that were high enough to raise the statistics for mean usage on the minimum threshold plot but were not high enough to be detected and removed by the processing techniques described in Section 4.1. This phenomenon also has an impact on the 24-hour plot shown in Figure 31, in which only the minimum threshold plots appear to have this anomaly. To improve readability of the week-long plots, the latter anomalies are cut off by the top of the graphs, since this data is not relevant to analysis.

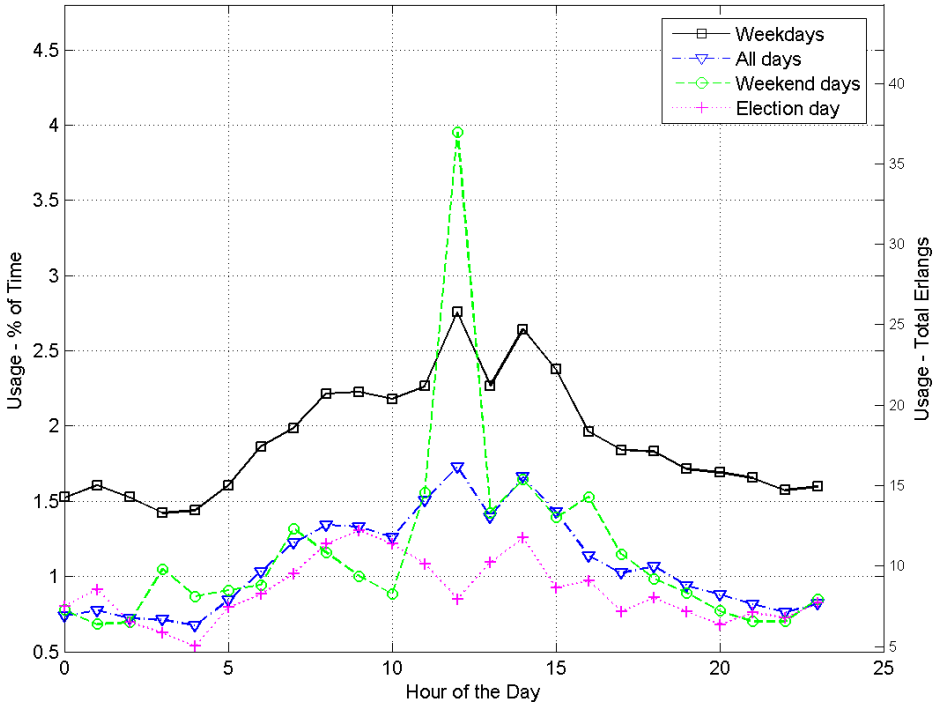


Figure 29. *Band Occupancy by Time-of-Day* (percent of time and total Erlangs) during different 24-hour time scenarios in the 162–174 MHz band (excluding HOCs; minimum threshold).[14]

[14] An anomaly occurs at midday on weekend days in which the data approaches 4 percent usage. Examining this data in greater detail revealed a period of increased noise on Sunday that was high enough to raise the statistics for mean usage on the minimum threshold plot but were not high enough to be detected and removed by the processing techniques described in Section 4.1.

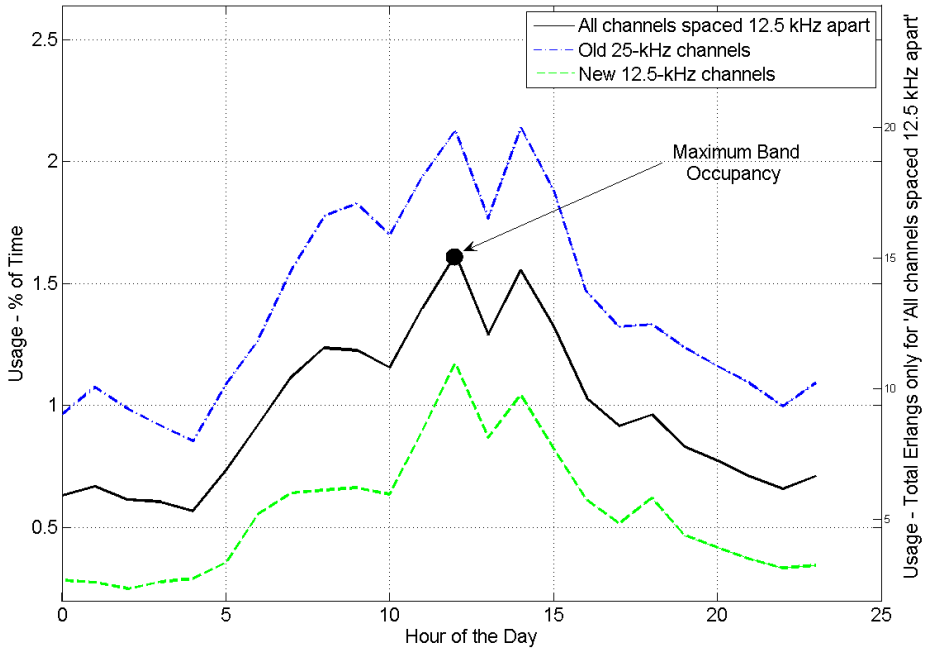


Figure 30. *Band Occupancy by Time-of-Day* (percent of time and total Erlangs) during the course of 24 hours, independent of the date, for different channelization scenarios in the 162–174 MHz band (excluding HOCs; minimum threshold).[15]

[15] As discussed earlier, the processed data in Figures 30 and 31 contain measurements on both Specific Location Assignments and Area Assignments. The *Maximum Band Occupancy* in Figure 30, which includes both types of assignments, is about 1.6 percent at 12 noon. The *Maximum Band Occupancy* associated with each type of assignment ("Specific Location" vs "Area") will be different, since Area Assignments may or may not have been active during the measurement period within the measurement coverage area. A search of the GMF by OSM revealed that the number of Specific Location Assignments deemed to be visible to the measurement system is 511, and when the measured data were examined on a channel-by-channel basis for that specific time (12 pm), it was determined that total number of Erlangs for Specific Location Assignments was 10.98. Therefore, the *Maximum Band Occupancy* for Specific Location Assignments was determined to be 2.1 percent.

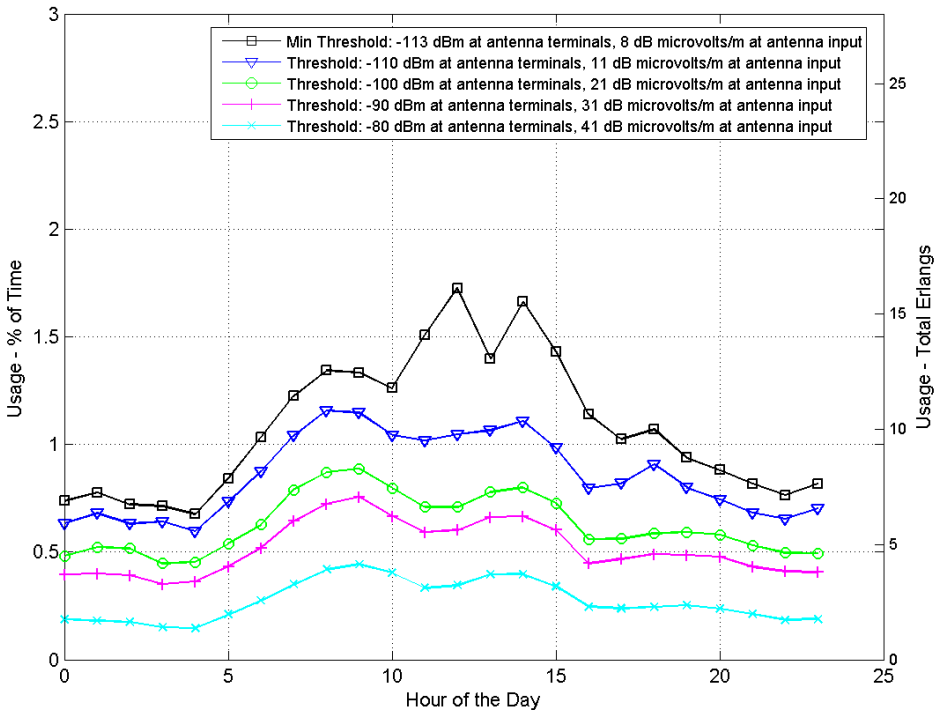


Figure 31. *Band Occupancy by Time-of-Day* (percent of time and total Erlangs) using different thresholds, independent of the date, for all 934 channels in the 162–174 MHz band (excluding HOCs).

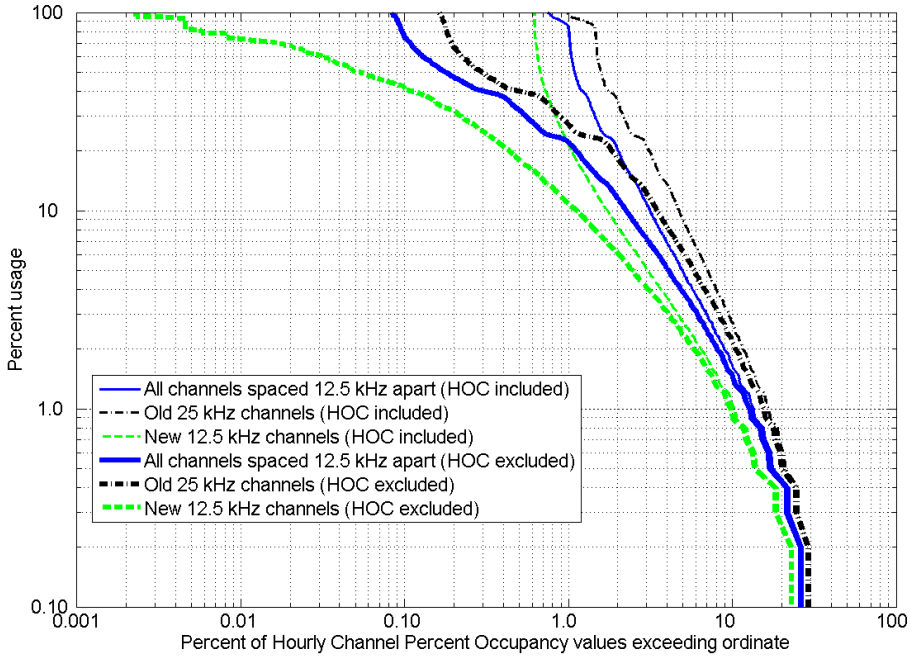


Figure 32. Percent of *Hourly Channel Percent Occupancy* values exceeding a given percent usage over the course of the measurements for the 162–174 MHz band (minimum threshold).

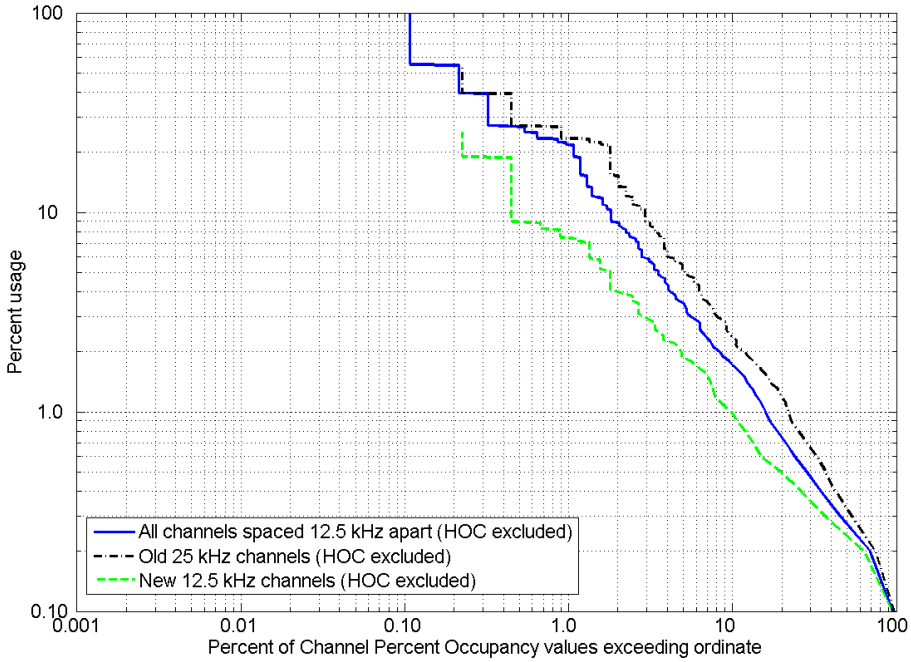


Figure 33. Percent of channels exceeding a given percent usage for *Channel Percent Occupancy* over the course of the measurements for the 162–174 MHz band (minimum threshold).

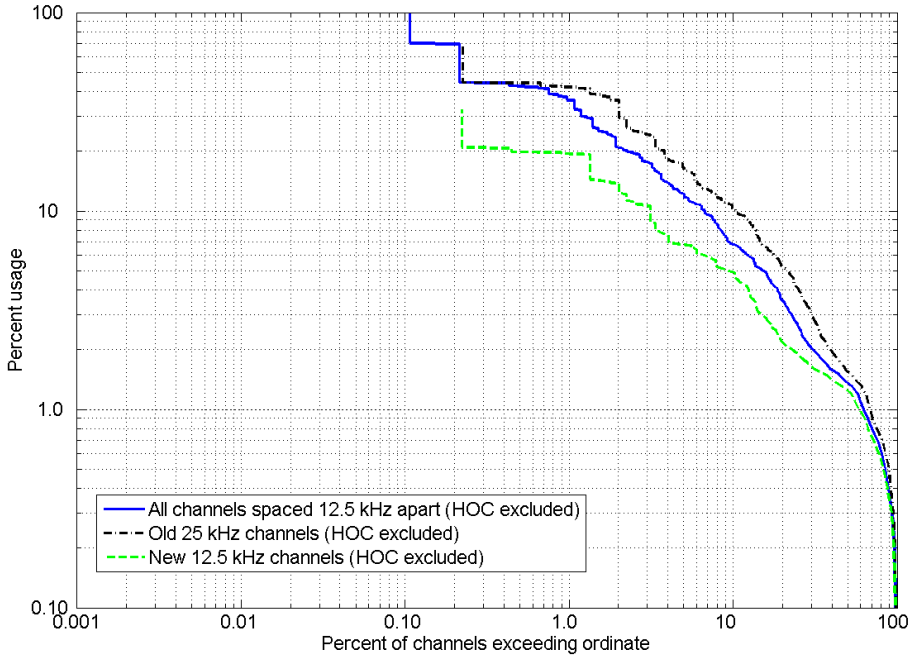


Figure 34. Percent of channels exceeding a given percent usage for the *Busiest Usage by Time-of-Day for Each Channel* during weekdays only in the 162–174 MHz band (minimum threshold).

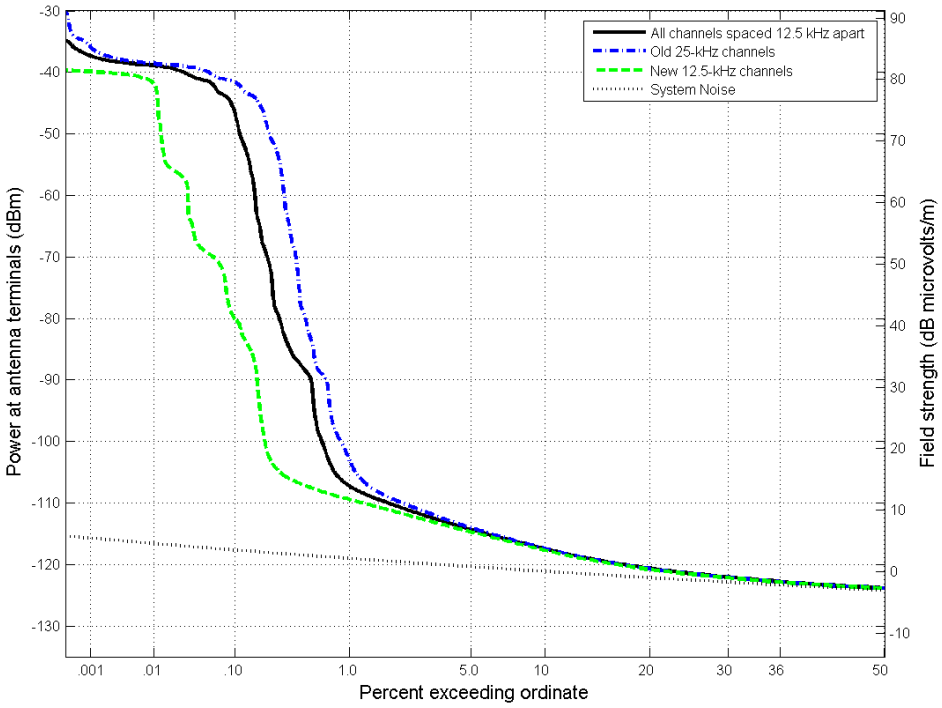


Figure 35. APDs of *Channel Power Values* for channels in the 162–174 MHz band – entire week, independent of date or time for different channelization (excluding HOCs; minimum threshold).

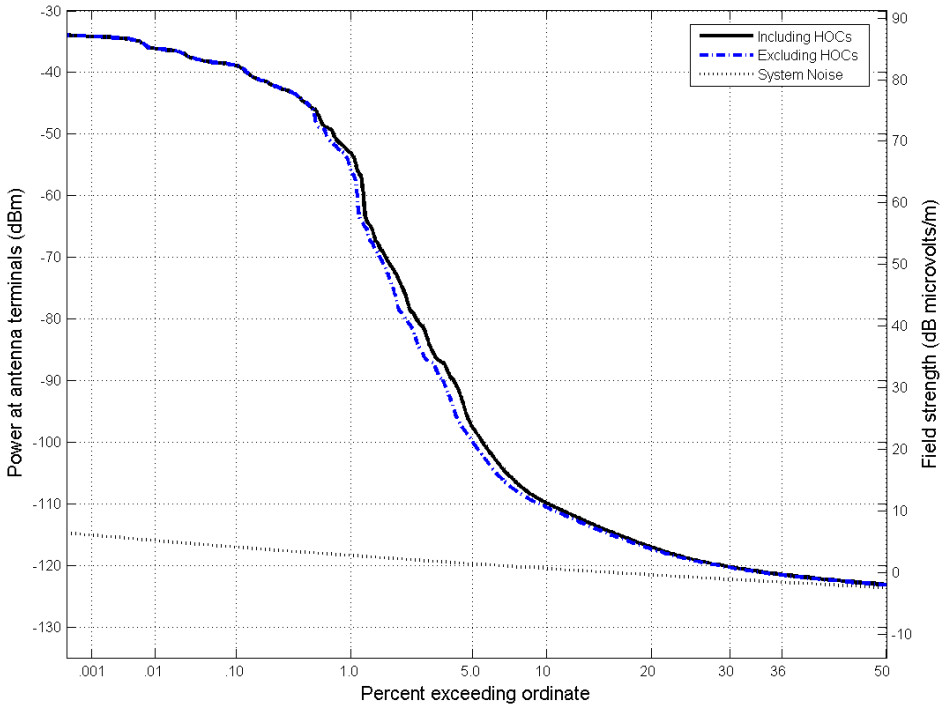


Figure 36. APDs of *Channel Power Values* for all channels spaced 12.5 kHz apart in the 162–174 MHz band for the busiest hour during the entire week independently for each frequency for different HOC scenarios (minimum threshold).

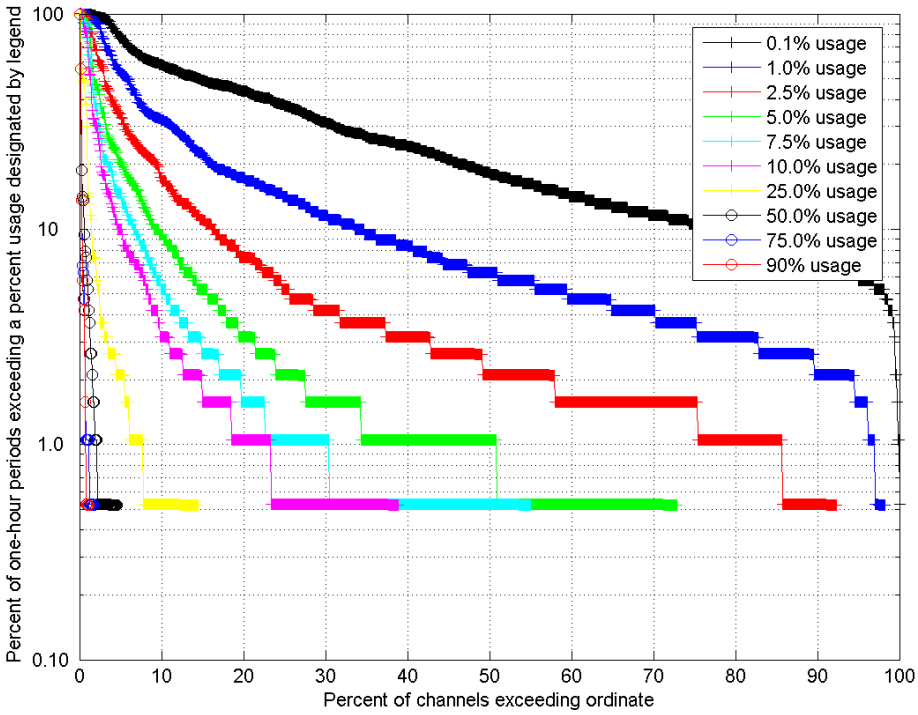


Figure 37. Cumulative distribution of the percent of channels that exceed a given percent of hours at greater than or equal to a given *Hourly Channel Percent Occupancy* (designated by legend) for all channels in the 162–174 MHz band (excluding HOCs; minimum threshold, entire week).[16]

[16] Discrete steps in the "percent of hourly periods" occur because there are a discrete number of one-hour time slots over the course of the measurement. Since there were approximately 196 hours of measurement during the course of the 8 days, a single one-hour time slot represents a "percent of hourly periods" of 0.51%, two hours represents 1%, and three hours represents 1.5% (consistent with the discrete steps seen in the figure above).

5.8.2 Results for 406–420 MHz Band

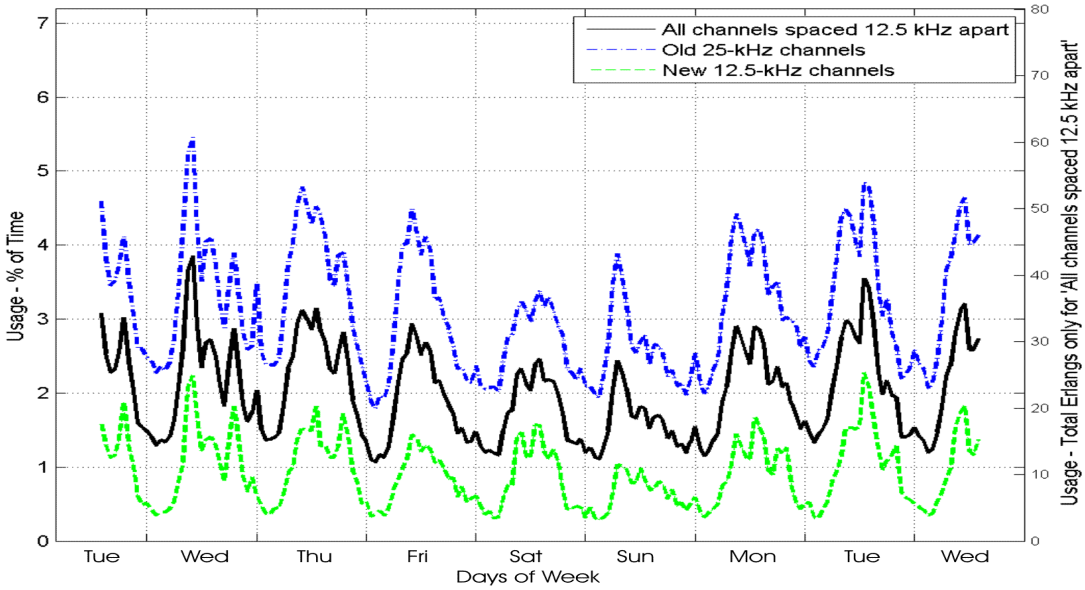


Figure 38. *Hourly Band Usage* (percent of time and total Erlangs) during the course of the measurements for the 406–420 MHz band (excluding HOCs; minimum threshold).

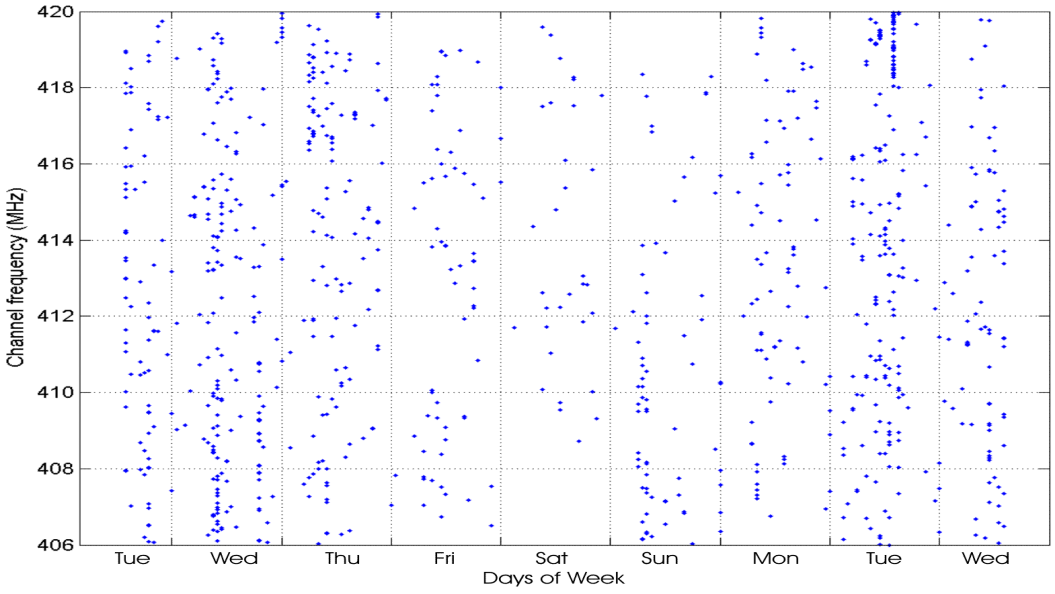


Figure 39. *Busiest Hour of the Week for Each Channel* in the 406–420 MHz band.

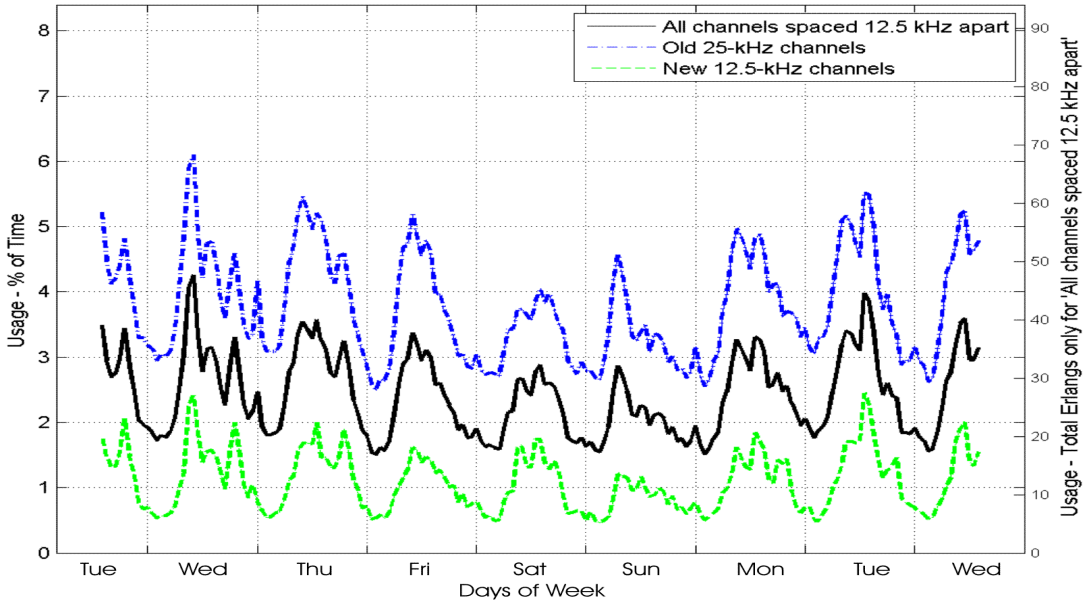


Figure 40. *Hourly Band Usage* (percent of time and total Erlangs) during the course of the measurements for the 406–420 MHz band (including HOCs; minimum threshold).

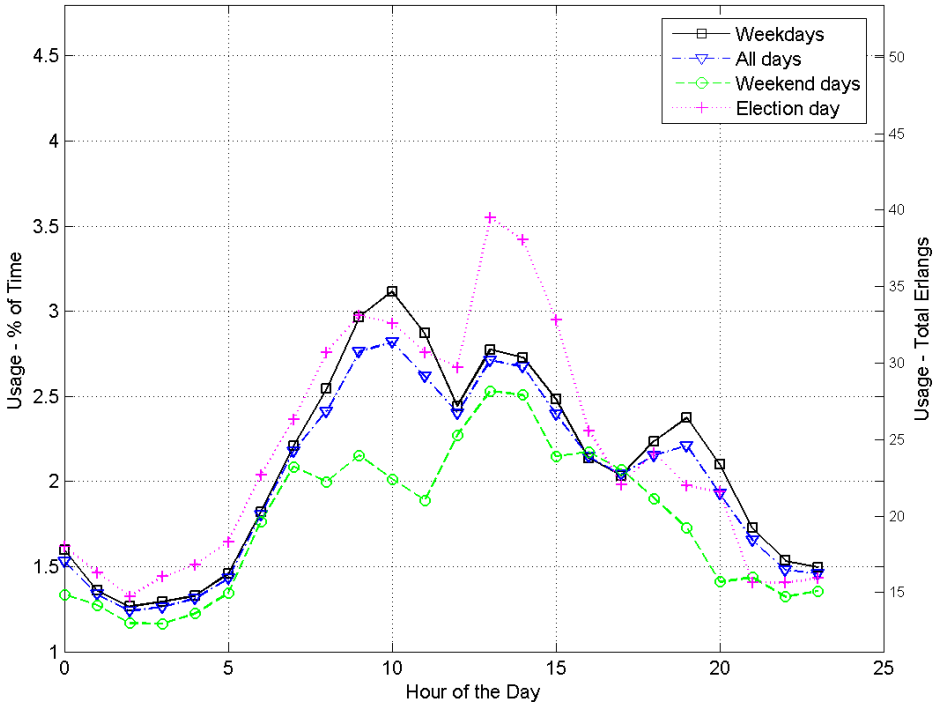


Figure 41. *Band Occupancy by Time-of-Day* during different 24-hour time scenarios in the 406–420 MHz band (excluding HOCs; minimum threshold).

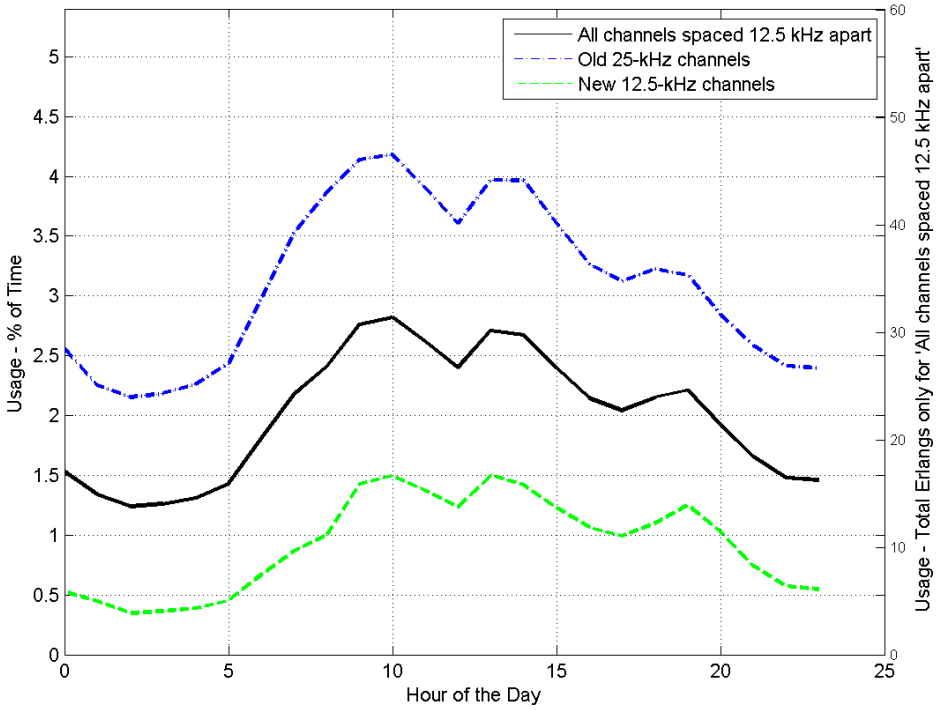


Figure 42. *Band Occupancy by Time-of-Day* (percent of time and total Erlangs) during the course of 24 hours, independent of the date, for different channelization scenarios in the 406–420 MHz band (excluding HOCs; minimum threshold).

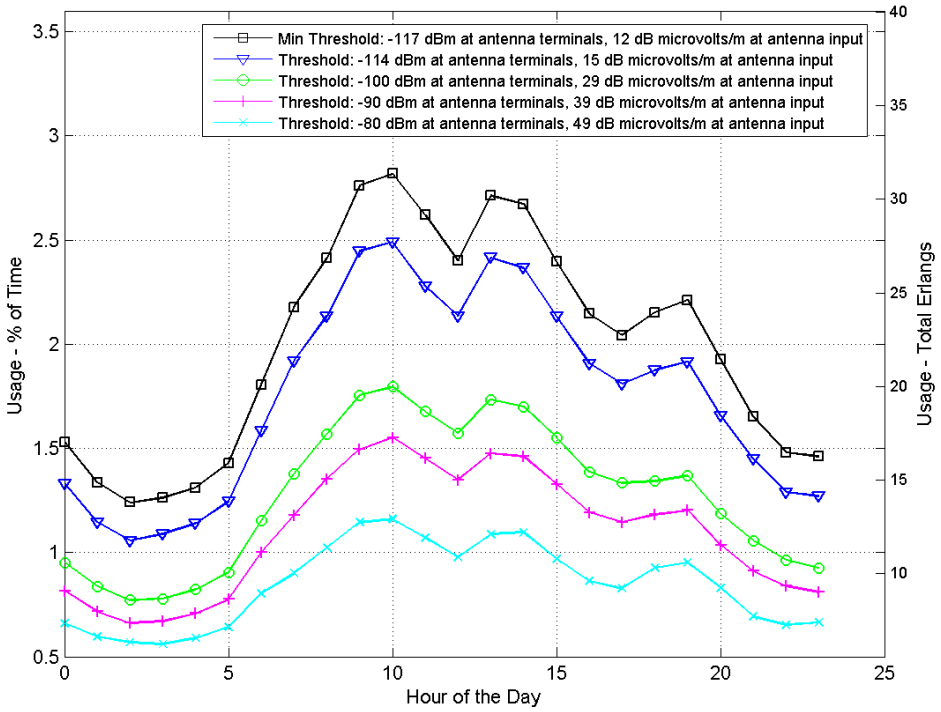


Figure 43. *Band Occupancy by Time-of-Day* (percent of time and total Erlangs) using different thresholds, independent of the date, for all 1113 channels in the 406–460 MHz band (excluding HOCs).

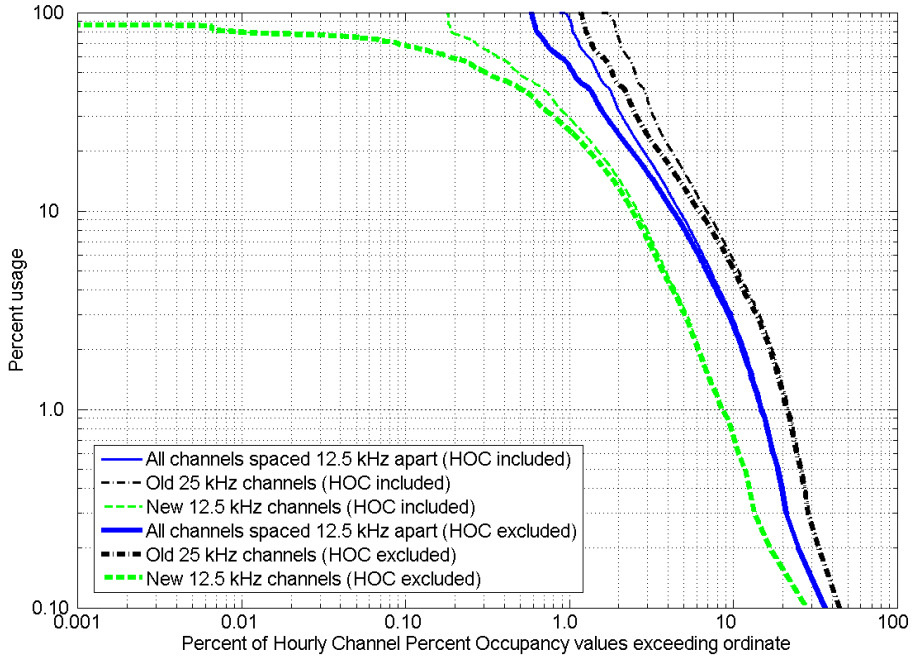


Figure 44. Percent of *Hourly Channel Percent Occupancy* values exceeding a given percent usage over the course of the measurements for the 406–420 MHz band (minimum threshold).

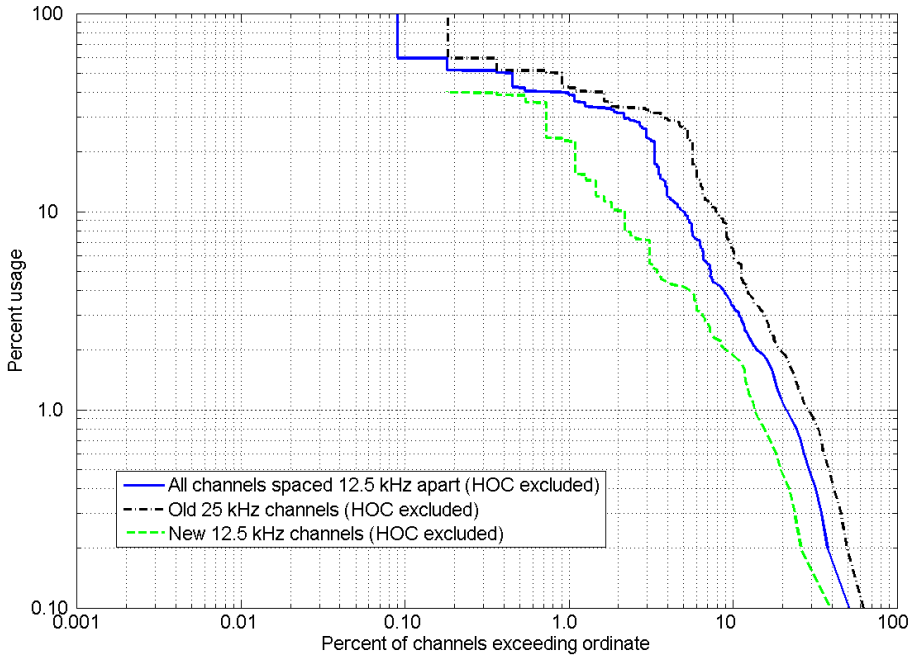


Figure 45. Percent of channels exceeding a given percent usage for *Channel Percent Occupancy* over the course of the measurements for the 406–420 MHz band (minimum threshold).

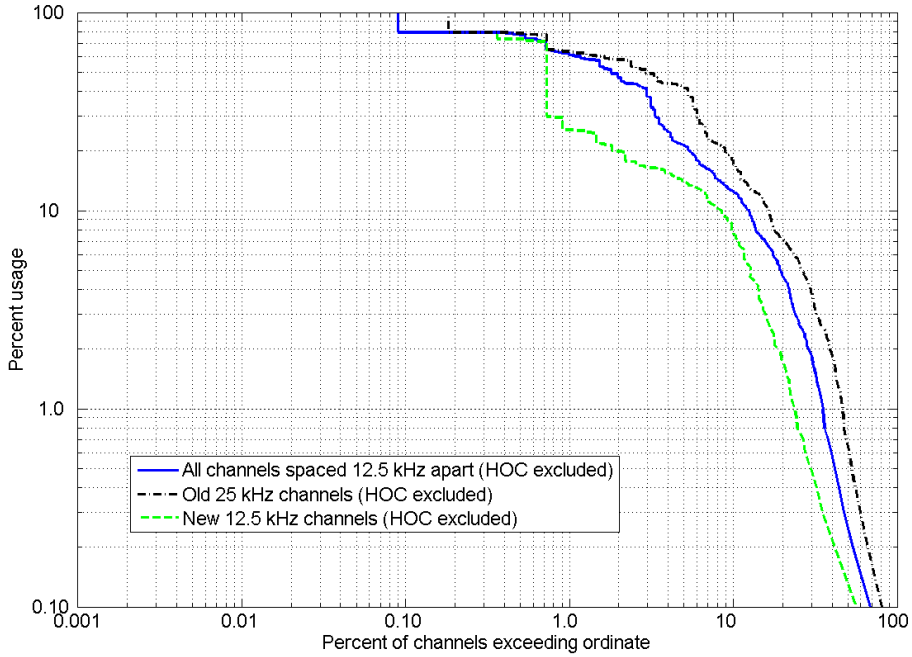


Figure 46. Percent of channels exceeding a given percent usage for the *Busiest Usage by Time-of-Day for Each Channel* during weekdays only in the 406–420 MHz band (minimum threshold).

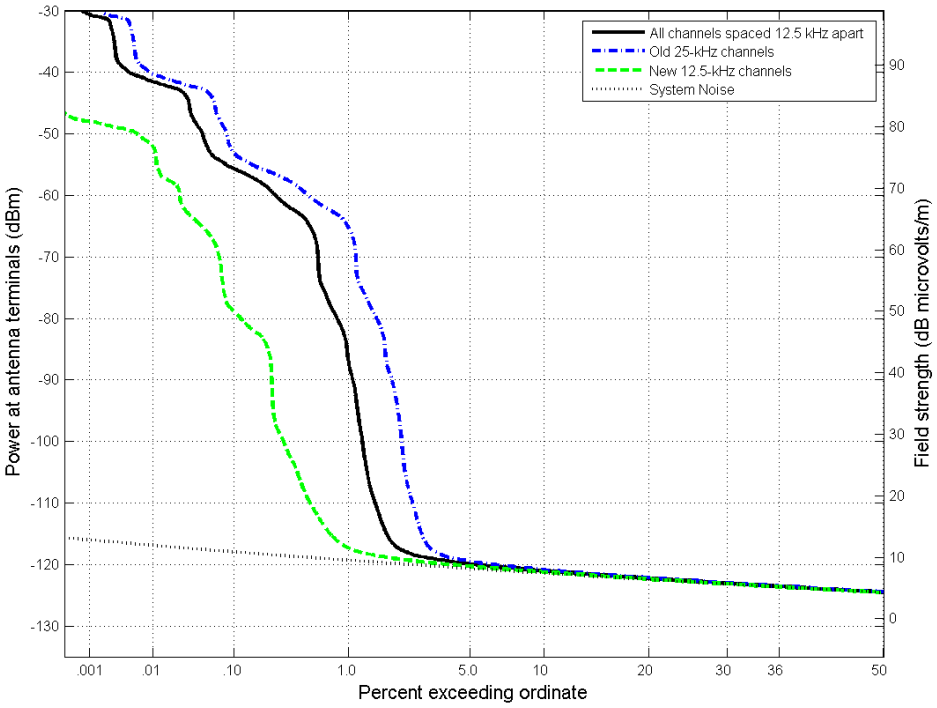


Figure 47. APDs of *Channel Power Values* for channels in the 406–420 MHz band – entire week, independent of date or time for different channelization (excluding HOCs; minimum threshold).

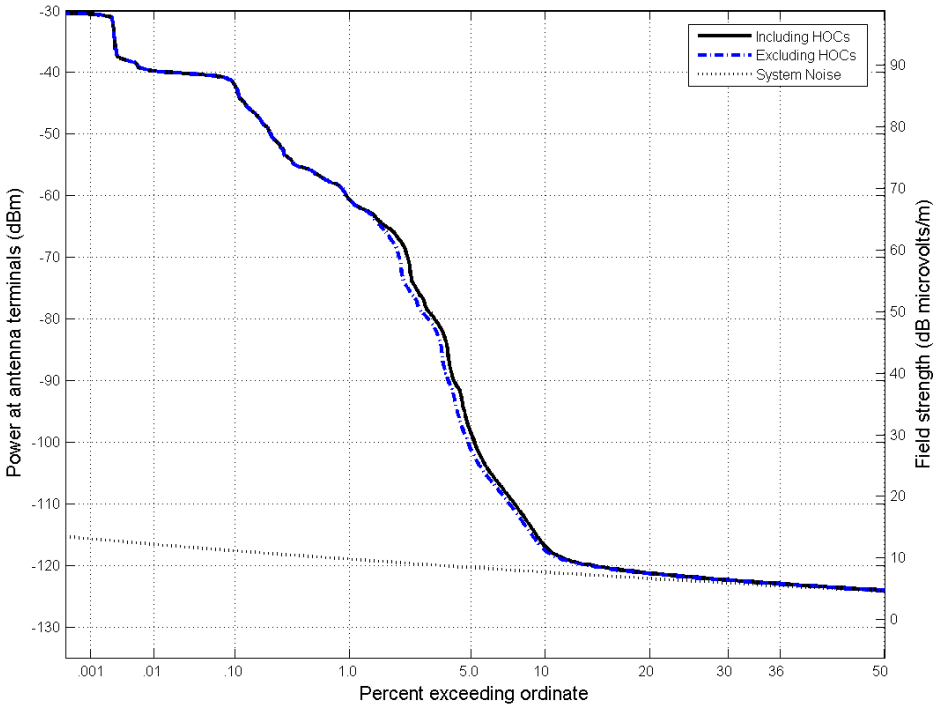


Figure 48. APDs of *Channel Power Values* for all channels spaced 12.5 kHz apart in the 406–420 MHz band for the busiest hour during the entire week independently for each frequency for different HOC scenarios (minimum threshold).

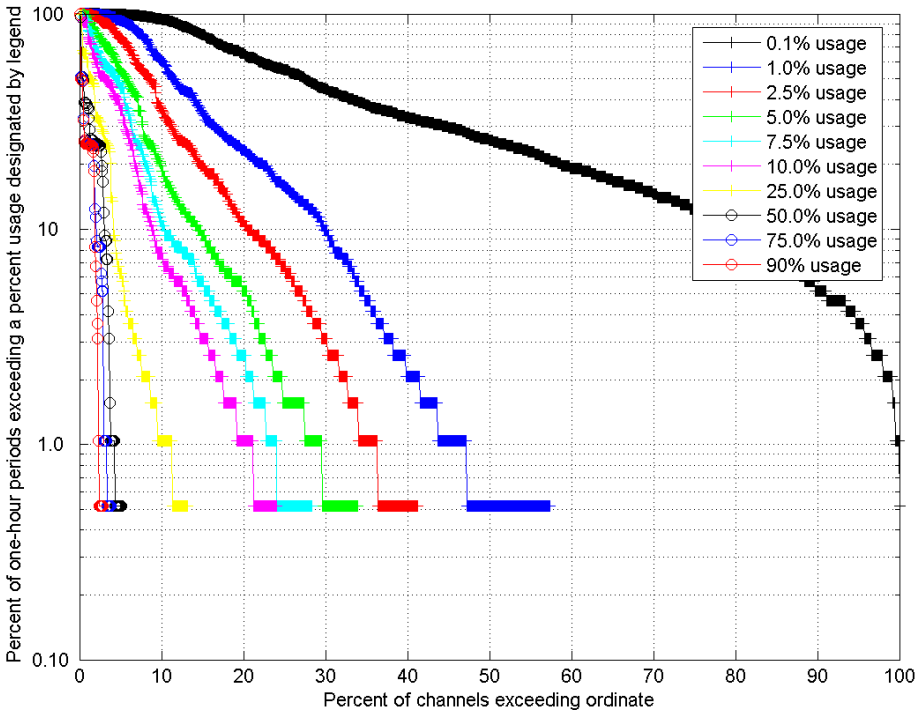


Figure 49. Cumulative distribution of the percent of channels that exceed a given percent of hours at greater than or equal to a given *Hourly Channel Percent Occupancy* (designated by legend) for all channels in the 406–420 MHz band (excluding HOCs; minimum threshold).