NTIA Technical Report TR-08-455

Measurements to Characterize Land Mobile Channel Occupancy for Federal Bands 162–174 MHz and 406–420 MHz in the Denver, CO Area

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report series

U.S. DEPARTMENT OF COMMERCE • National Telecommunications and Information Administration

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U.S. DEPARTMENT OF COMMERCE
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for Communications and Information

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ACRONYMS

APD	amplitude probability distribution
dB	decibel
dBi	decibels relative to isotropic
dBm	decibels relative to 1 milliwatt
dBµV/m	decibels relative to 1 microvolt per meter
GMF	Government Master File
HOC	high occupancy channel
ITS	Institute for Telecommunication Sciences
kHz	kilohertz
km	kilometer
LMR	Land Mobile Radio
m	meter
MHz	megahertz
NTIA	National Telecommunications and Information Administration
OSM	Office of Spectrum Management
PSWAC	Public Safety Wireless Advisory Committee
RF	radio frequency
RSMS	Radio Spectrum Measurement Science
RSMS-4	Radio Spectrum Measurement Science fourth generation measurement system
W	watt

DEFINITIONS

Amplitude Probability Distribution (APD): A cumulative probability distribution plot representing the probability of exceeding a given level of power, where the y-axis displays power and the x-axis displays the probability expressed on a Rayleigh scale. The tutorial in Appendix A of [1] provides a detailed description of APDs.

Area Assignments: Frequency assignments in the Government Master File that do not have specific coordinates and authorize base station and/or mobile stations to operate anywhere within a defined geographic area (e.g., United States and Possessions).

Average of Busiest Usage by Hour: Determined by computing the average of the *Busiest Usage by Time-of-Day for Each Channel* values across all channels in the band, resulting in a single value for the entire band. The *Average of Busiest Usage by Hour* values are displayed in Tables A-1, A-2, A-4, and A-5.

Band Occupancy by Time-of-Day: 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. *Band Occupancy by Time-of-Day* values are displayed in Figures 7 through 9 and 19 through 21.

Busiest Usage by Time-of-Day for Each Channel: Determined for each channel by identifying the *Usage by Time-of-Day* value that is the largest out of the 24 values. There is only one *Busiest Usage by Time-of-Day* value for each channel. The *Busiest Usage by Time-of-Day for Each Channel* values are summarized in Figures 12 and 24.

Busiest Hour of the Week for Each Channel: Determined for each channel by identifying the time and date at which the highest *Hourly Channel Percent Occupancy* value occurs. During the week, channels will typically have a different date and time when the usage is busiest. *Busiest Hour of the Week for Each Channel* values are displayed in Figures 6 and 17.

Channel Percent Occupancy: Computed for each channel by determining the percent of *Channel Power Values* that exceed a detection threshold for each 1-second acquisition every day of the measurement period. For example, if 2,280 out of the 76,000 total *Channel Power Values* for a specific channel are above the detection threshold, then the channel occupancy is 3 percent at that detection level for the specified channel. *Channel Percent Occupancy* values are summarized in Figures 11 and 23.

Channel Power Readings: The amount of received power on an individual channel measured using an Agilent E4440A Spectrum Analyzer in a resolution bandwidth of 5.5 kHz. Five of these basic measurements are used to compute a *Channel Power Value*, which is the building block for all further analysis and computations.

Channel Power Value: Determined by computing the median of 5 consecutive individual *Channel Power Readings* measured within a 1-second measurement period. The median value of the 5 independent measurements made for each channel is selected as the single value of measured power for that channel during that 1-second measurement period. All further processing of measured data is based on this median-of-5 measurement technique. For example, if the 5 individual *Channel Power Readings* are -77, -70, -75, -69, and -73 dBm, the median value is -73 dBm. This value is computed for each channel at 1-second intervals, in the 4-minute measurement period for each 5-MHz frequency block. *Channel Power Values* are summarized in Figures 13, 14, 25, and 26.

Channel Power Values in an Hour: A set of individual *Channel Power Values* measured over a 1-hour period. This is represented by a set of data that typically contains either 240 (162–174 MHz band) or 480 (406–420 MHz band) median-of-5 *Channel Power Values* for that hour of that day for a specific channel.

Erlangs: A traffic equivalent to full time occupancy of a channel for an hour – for instance, one channel used continuously for 60 minutes, or two channels with a combined occupancy of 60 minutes. In this report, the number of Erlangs is determined by multiplying the percent usage by the total number of channels in the band.

High Occupancy Channel: A channel that exceeds the detection threshold for a large percent of the time (defined in this paper as >80 percent of time).

Hourly Band Usage: Determined by averaging all of the *Hourly Channel Percent Occupancy* values in a given hour of a given day for all of the channels in the band. The *Hourly Band Usage* is displayed in Figures 5, 16, 18, A-1, and A-2.

Hourly Channel Percent Occupancy: Computed for each channel by determining the number of *Channel Power Values in an Hour* for a given channel that exceed a detection threshold. For example, if 14 out of 480 total *Channel Power Values in an Hour* are above the detection threshold, then the channel occupancy is 3 percent at that detection level, for the specified hour and channel. *Hourly Channel Percent Occupancy* values are summarized in Figures 10, 15, 22, and 27.

Hydrology Channel: A channel used for the automatic transmission of hydrologic or meteorological data, or both. Hydrology channels are present in the 162–174 MHz and the 406–420 MHz LMR bands but are not considered LMR users.

Maximum Band Occupancy: The maximum of all *Band Occupancy by Time-of-Day* values. This is shown in Figures 8 and 20.

Occupancy: Channels are considered occupied (i.e., in use) whenever the channel contains radio frequency power above a certain received detection threshold level. By some definitions a channel may be considered "in use" even if no traffic is being carried during the time of measurement. For instance, a channel being used by a Secret Service agent protecting the President may not carry traffic (not occupied) unless there is an emergency. However, the channel is "in use" in the sense that personnel are monitoring the channel and ready to take action should a situation require it. In this report, "usage" is used interchangeably with the term "occupancy," which means "carrying traffic" — not simply being monitored.

Percent Band Usage: Determined by computing the mean of all *Hourly Channel Percent Occupancy* values for all channels during the measurement period. The measurement periods examined include all days, weekdays only, and weekend days. *Percent Band Usage* values are shown in Tables A-1 through A-6.

Specific Location Assignments: Frequency assignments in the Government Master File that have specific coordinates (latitude and longitude) for the location of the base station and a radius of operation for the associated mobile and portable stations.

Trunking: The method used in some modern communications systems in which frequency channels are assigned dynamically as required, usually when there are more users than available frequency channels. This allows time sharing of the same frequencies by multiple users, thus improving channel usage efficiency. Typically, a control channel is used to make initial contact, after which a frequency channel is assigned to the user's radio device during the course of the connection. This technique is utilized in most modern cellular phone services, since there are far more users than available frequencies.

Usage by Time-of-Day for Each Channel: Determined for each channel by computing the average of the *Hourly Channel Percent Occupancy* values for each specific hour of the day for the corresponding measurement period (e.g., all days, weekdays, and weekend days). For example, channel 1 will have 24 different *Usage by Time-of-Day for Each Channel* values, each for a different hour of the day. These 24 values represent the mean usage for that specific time of day over the course of the several days of the measurements.

Usage: Refer to the definition for "Occupancy."

EXECUTIVE SUMMARY

In May 2003, President Bush established the Spectrum Policy Initiative to promote the development and implementation of a United States spectrum policy for the 21st century. In response to the Spectrum Policy Initiative, the Secretary of Commerce established a Federal Government Spectrum Task Force and initiated a series of public meetings to address policies affecting spectrum use by the Federal, state, and local governments, and the private sector. The recommendations resulting from these activities were included in two reports released by the Secretary of Commerce in June 2004. Based on the recommendations contained in these reports, the President directed the Federal Agencies on November 30, 2004 to plan the implementation of the 24 recommendations contained in the reports. One of the recommendations directed the National Telecommunications and Information Administration (NTIA) to develop analytic approaches, software tools, and engineering techniques for evaluating and improving the efficiency and effectiveness of Federal spectrum use.

To satisfy one of the goals of that recommendation, NTIA's Institute for Telecommunication Sciences (ITS) undertook a series of channel occupancy measurements in Arvada in the Denver, Colorado metropolitan area from October 26 to November 3, 2005 in the Land Mobile Radio (LMR) bands 162–174 and 406–420 megahertz (MHz). The purpose of these measurements was twofold: first, to evaluate and refine LMR channel occupancy measurement techniques, previously developed for the Washington, DC LMR measurements performed in 2004; secondly, to gather actual data on the usage of these bands in the Denver metropolitan area. The data gathered for this area and these bands will be used for further analyses of other aspects of the Presidential Spectrum Policy Initiative.

Measurements of LMR channels were conducted at a site on the grounds of the Exempla Colorado Lutheran Home facility, at a location in Arvada overlooking the Denver metropolitan area, using the fourth generation Radio Spectrum Measurement Science (RSMS) system. The measurements were conducted 24 hours per day over the course of 8 consecutive days. The measured data was then processed at the ITS Laboratory in Boulder, Colorado.

The measurement system was designed to have a spatial coverage area of approximately 100-kilometer (km) radius for base stations, 50-km radius for mobile units, and 25-km radius for handheld units. The results are reported in terms of channel usage for designated LMR channels, irrespective of whether the individual channels have been assigned or not. The purpose is to determine, given a specific threshold sensitivity, whether LMR channels at a location overlooking the Denver metropolitan area are being used at that location and to what extent.

There are four types of data summarized in this report: 1) mean channel usage, 2) mean busiest-hour statistics, 3) power-level statistics, and 4) statistics on percent of channels (and hourly channel usage) exceeding a given percent usage.

The measured data contains information on channel usage for two types of frequency assignments: Specific Location Assignments and Area Assignments. Specific Location Assignments have specific coordinates (latitude and longitude) for the location of the base station and a radius of operation for associated mobile and portable stations. Area Assignments do not have specific coordinates and authorize base and mobile stations to operate anywhere

within a specific geographic area (e.g., United States and Possessions). These two types of frequency assignments were not distinguished during analyses; therefore the usage statistics are based on both types of assignments.

For the 162–174 MHz band, the mean percent time that all of the channels in the band are being used for each hour (referred to in this report as *Band Occupancy by Time-of-Day*) varied between 0.6 and 1.5 percent, with the busiest hours being between 6 a.m. and 6 p.m. For the 406–420 MHz band, the value was 0.6 to 1.0 percent with the busiest hours being between 6 a.m. and 3 p.m.

The *Band Occupancy by Time-of-Day* for conventional LMR systems can be compared to allowable call-blockage (typically defined as Grade of Service) as recommended in the Final Report of the Public Safety Wireless Advisory Committee (PSWAC)[3]. In that report, the PSWAC recommends that call-blockage 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 systems where channels are assigned statically. Since the existing systems measured in the 162–174 MHz band are conventional systems, the measured channel usage during the busiest hour of 1.3 percent is consistent with the recommendations made by the PSWAC.

In the 162–174 MHz band, the diurnal behavior was similar, irrespective of whether they were measured for all days, weekdays, or weekends. The highest overall usage occurred on weekdays (Figure 7), with the normal daylight hours showing the most activity. Curiously, there was a duration of time in the mid-morning hours where the weekend use dominated the weekday use.

In the 406–420 MHz band, a distinct difference in diurnal pattern can be noted between the weekday and weekend cases (Figure 19), with the usage being higher during normal daylight hours on the weekdays and the usage being higher outside of normal daylight hours on weekends. Usage on the weekends is decreased by a factor of as much as 2 during normal daylight hours when compared to weekdays. There was a small duration of time in the early morning hours where usage was higher for the weekend case when compared to the weekday case.

It should be noted that most of the channels in these bands are statically assigned to networks or individual users, in contrast to dynamically assigned as is the case with trunked systems, where there is time sharing of each frequency channel by multiple users. Some of these assigned 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. In addition, none of these measurements were made during a major emergency that might have greatly increased the use of radio channels.

The data can be used for specifying the overall performance objectives of a hypothetical communications system using a different technology (e.g., trunking). By designing the hypothetical system to provide the same overall communications capability as the existing LMR systems, the existing and hypothetical systems could then be compared to examine relative total spectrum usage (number of channels required for each system). For example, in NTIA Report

08-451 [4], measurements of LMR usage for the 162–174 MHz band in the Washington, DC metropolitan area, along with the government master file (GMF) data, were used to design the alternative LMR trunked radio systems.

In comparing the results of the Washington, DC measurements to the results of the Denver measurements, similar data on usage were obtained for the 162–174 MHz band for all channels spaced 12.5 kHz apart. The difference in usage between the two sets of measurements was only 0.3 percent. The percentage distributions for when the usage peaked are also very similar to each other. These consistent results imply that the technology and data process techniques used for the Washington, DC and Denver measurements can be used for future LMR measurements at other locations. For the 406–420 MHz band, the difference in usage between the two measurements was 1.65 percent. It is unknown why this occurred and the reasons for it may be investigated. It is possible that this difference is merely due to the fact that there are more Federal users in the Washington, DC area than in the Denver metropolitan area.

The intent of these measurements was not to examine details of performance and use for the characterization of individual channels, but rather, for the channels in aggregate. Individual channel information, as well as more extensive measurements, would be required for a detailed engineering design for a next generation system.

MEASUREMENTS TO CHARACTERIZE LAND MOBILE CHANNEL OCCUPANCY FOR FEDERAL BANDS 162–174 MHZ AND 406–420 MHZ IN THE DENVER, CO AREA

John E. Carroll, J. Randy Hoffman, and Robert J. Matheson[1]

This report describes field measurements to characterize Land Mobile Radio (LMR) channel occupancy of Federal bands 162–174 megahertz (MHz) and 406–420 MHz at a single location overlooking the Denver, Colorado metropolitan area. This is part of the National Telecommunications and Information Administration effort to improve the spectrum efficiency of Federal radio usage. Measurements of the received radio traffic levels in these LMR frequency bands were performed over an 8-day period for the purpose of determining radio channel usage within the receiver spatial coverage of approximately 100-kilometer (km) radius for base stations, 50-km radius for mobile units, and 25-km radius for handheld units. The measurements were made using newly developed techniques that digitize as much as a 5-MHz segment of spectrum and process it to obtain simultaneous signal levels of up to 400 individual LMR channels. These techniques provided faster measurements, but also allowed enhanced post-processing of the data to remove effects of impulsive noise-like sources.

Key words: channel occupancy; channel usage; Federal radio usage; Land Mobile Radio (LMR); measurements; spectrum efficiency

1 INTRODUCTION

In May 2003, President Bush established the Spectrum Policy Initiative to promote the development and implementation of a United States spectrum policy for the 21st century. In response to the Spectrum Policy Initiative, the Secretary of Commerce established a Federal Government Spectrum Task Force and initiated a series of public meetings to address policies affecting spectrum use by the Federal, state, and local governments, and the private sector. The recommendations resulting from these activities were included in two reports released by the Secretary of Commerce in June 2004. Based on the recommendations contained in these reports, the President directed the Federal Agencies on November 30, 2004 to plan the implementation of the 24 recommendations contained in the reports. One of the recommendations directed the National Telecommunications and Information Administration (NTIA) to develop analytic approaches, software tools, and engineering techniques for evaluating and improving the efficiency and effectiveness of Federal spectrum use.

As discussed in the Spectrum Policy Initiative reports, the radio frequency (RF) spectrum is a critical resource that is used by the Federal Government to perform congressionally mandated

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missions. Efficient use of the spectrum is one of the cornerstones for obtaining maximum usage of the available spectrum. NTIA and other Federal Agencies realize that the primary way to satisfy the growing demand for spectrum in the Land Mobile Radio (LMR) frequency bands is to employ more spectrum efficient technologies.

As part of the effort to meet these objectives, ITS undertook a series of channel occupancy and usage measurements at a single location in the Denver metropolitan area in the 162–174 and 406–420 MHz LMR bands, the results of which are described in this report. The results of these channel occupancy measurements can further be used to specify the overall performance objectives of LMR systems employing different technologies (e.g., trunking).

1.1 Objective

There were two objectives for this project. The first objective was to monitor each assignable 12.5-kilohertz (kHz) and 25-kHz channel in the 162–174 MHz and 406–420 MHz bands in the Denver metropolitan area to determine the amount of time those channels contained power above specific thresholds, and to present statistical analysis of channel occupancy based on the number of occurrences exceeding the threshold. The second objective was to evaluate the measurement techniques and technology that were used to obtain the channel occupancy and usage data for the LMR bands.

1.2 Approach

Using the Radio Spectrum Measurement Science fourth generation measurement system (RSMS-4), the measurements were performed during the course of 8 consecutive days (October 26 to November 3, 2005). The measurement system was designed for a receiver spatial coverage of approximately 100-kilometer (km) radius for base stations and repeaters, 50-km radius for mobile units, and 25-km radius for portable units.[2] Data were acquired continuously, 24 hours per day, over the course of the 8-day period and then analyzed for Federal bands 162–174 MHz and 406–420 MHz to furnish channel loading statistics.

The measurements were made using newly developed techniques that digitize up to a 5-MHz segment of spectrum and process it to obtain simultaneous signal levels of up to 400 individual LMR channels. These techniques provided faster measurements and also allowed enhanced post-processing of the data to remove the effects of impulsive noise-like sources.

In this report, channels are considered to be occupied (i.e., in use) whenever the channel contains RF power above a certain received threshold level. The measurements were made and recorded so that variable threshold levels could be used for purposes of analyzing the effects of external noise-like sources and other factors. This definition of occupancy is generally consistent with other definitions of usage, although the choice of received power detection threshold levels is not necessarily uniform among researchers. By some definitions a channel may be considered “in use” even if no traffic is being carried during the time of measurement. For instance, a channel

[2] Typical reuse distances for base stations and repeaters are approximately 100km.

being used by a Secret Service agent protecting the President may not carry traffic (not occupied) unless there is an emergency. However, the channel is “in use” in the sense that personnel are monitoring the channel and ready to utilize it should a situation require it. In this report, “usage” is used interchangeably with the term “occupancy,” which means carrying traffic — not simply being monitored.

2 FIELD MEASUREMENTS DESCRIPTION

The measurements characterizing the Denver metropolitan area LMR occupancy were performed using the same methodology, hardware, configurations, and post-measurement techniques as the measurements to characterize the Washington DC area [2].

2.1 Site Selection

These LMR channel occupancy measurements were made using NTIA's RSMS-4 mobile laboratory at a site on the grounds of the Exempla Colorado Lutheran Home facility in Arvada, located at coordinates N39° 49' 39.28", W105° 4' 50.21" (Figure 1). The measurements were conducted 24 hours per day over the course of 8 consecutive days (Wednesday, October 26th to Thursday, November 3rd, 2005). The site was chosen for several reasons. It is elevated above the surrounding Denver metropolitan area and there is little LMR activity by mobile users in close proximity to the measurement site. In addition, there are relatively few strong base stations nearby that could overdrive or mask weaker signals from the measurement system.

Figure 1. RSMS mobile lab at measurement location.

Figure 2 shows an aerial view of the Denver metropolitan area with a marker designating the location of the measurement system. Figures 3 and 4 show predicted coverage plots using the Longley-Rice irregular terrain model (maximum receiver sensitivity)[3] for three different transmitter scenarios: 1) a 100-watt (W) transmitter with gain of 3 decibels relative to isotropic (dBi) and a 30-meter (m) antenna height (typical base station), 2) a 50-W transmitter with 0-dBi gain and a 1.5-m antenna height (typical mobile unit), and 3) a 10-W transmitter with -3-dBi gain and a 1.0-m antenna height (portable unit).[4] Figures 3 and 4 are for the 162–174 MHz and 406–420 MHz frequency bands respectively.

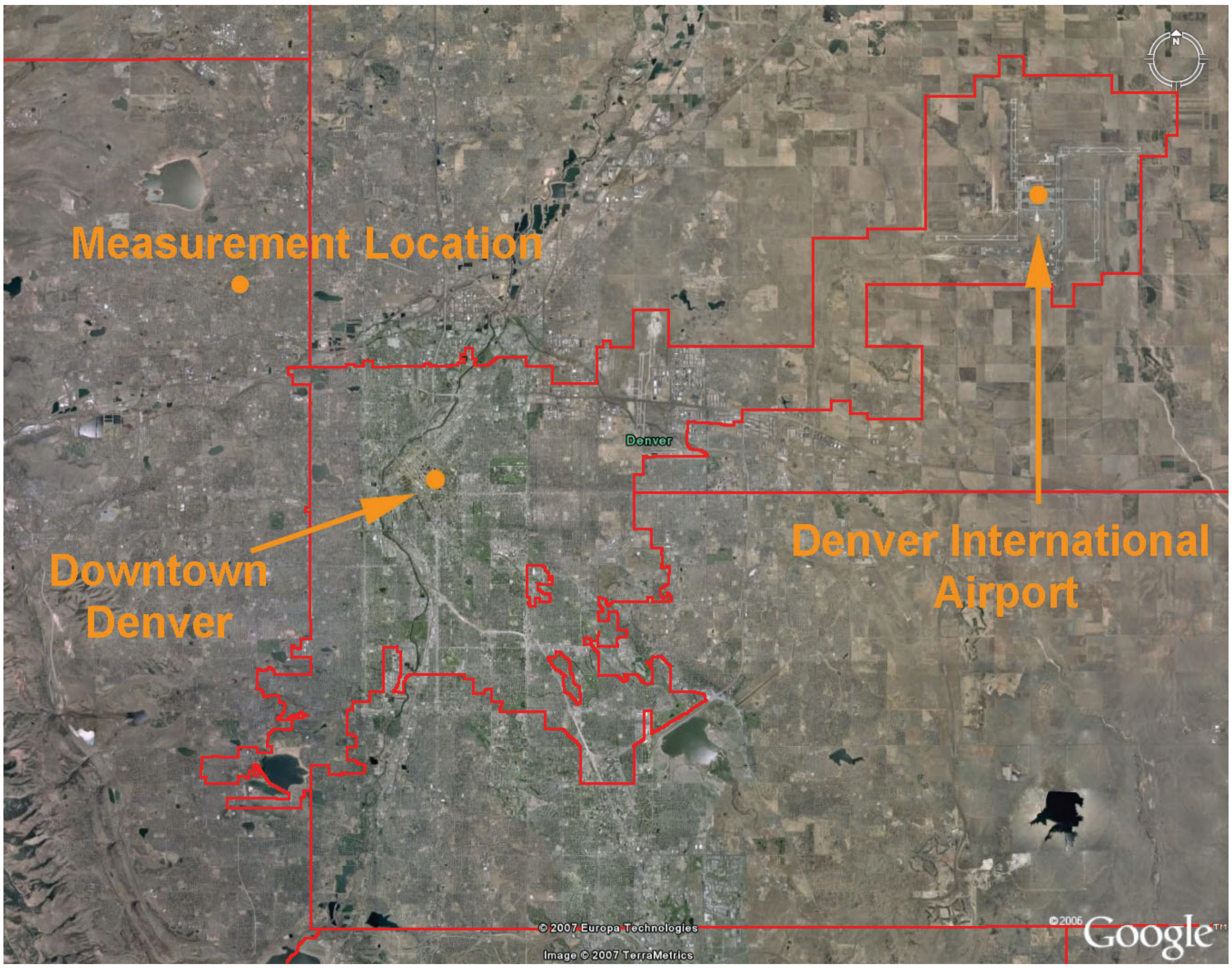

Figure 2. Aerial view of the Denver metropolitan area and the location of the measurement system.

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[3] The noise figures of the 162–174 MHz and the 406–420 MHz system are 13.9 dB and 9.9 dB respectively.
[4] More realistically, portable units have a maximum output of 5–6 W, and therefore, the coverage plots for portable units may be slightly less than that shown in Figures 3 and 4.

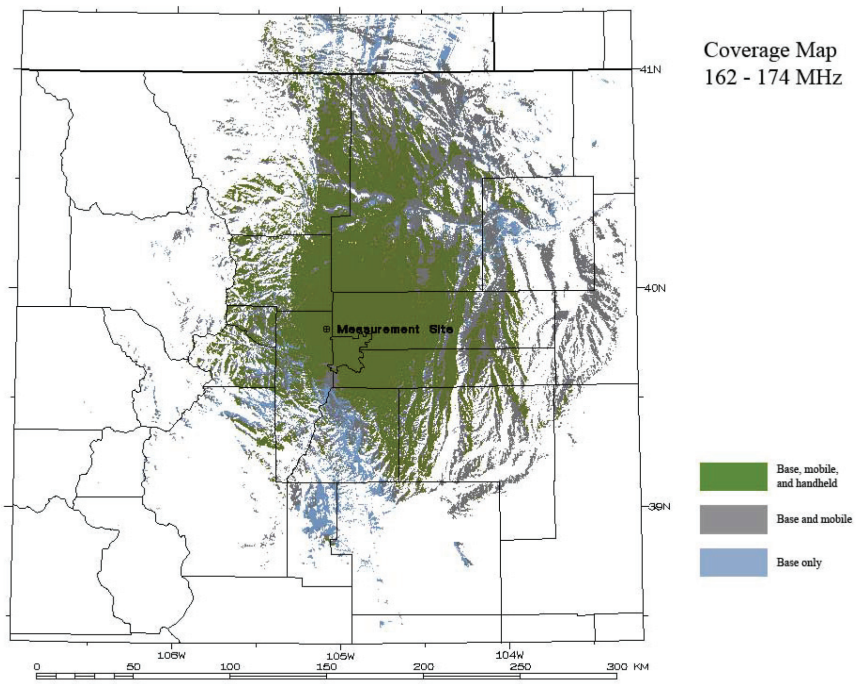

Figure 3. Coverage plot for the 162–174 MHz band using the minimum receiver threshold.

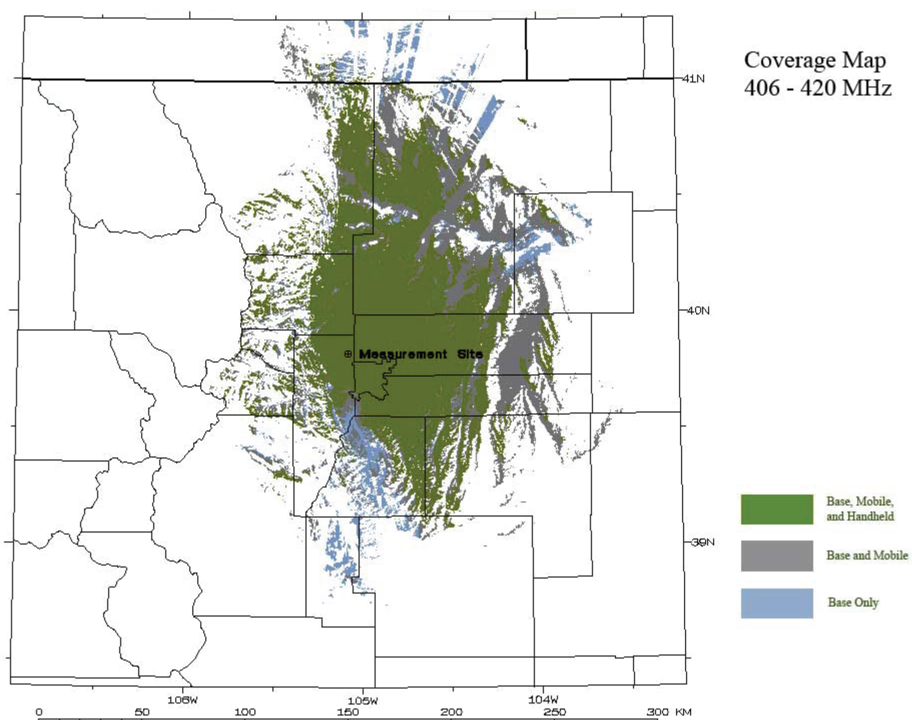

Figure 4. Coverage plot for the 406–420 MHz band using the minimum receiver threshold.

3 ANALYSIS AND RESULTS

Graphs and tables summarizing the usage for the different bands are included in this section, as well as in Appendix A. Since the same methodology, hardware, configurations, and post-measurement techniques were used as in the Washington DC area measurements, the detailed discussion of the various methods of statistical analysis is given in Section 5 of [2].

3.1 Time Scenarios

Both frequency groupings were analyzed according to five different time scenarios, as follows:

1. **Entire week**: Data analyzed as a whole for the entire week beginning Wednesday, October 26, 2005 at 2 p.m. through Thursday, November 3, 2005 at 10 a.m., independent of time or date.

2. **Date and time of day**: Data analyzed according to the date and time, in one-hour blocks.

3. **Time of day for any day**: Data analyzed according to time, in one-hour blocks, between 12 a.m. and 12 a.m. (24 hours later), independent of date or day.

4. **Time of day for weekdays**: Data analyzed according to time, in one-hour blocks, between 12 a.m. and 12 a.m. (24 hours later) only for weekdays, independent of the day.

5. **Time of day for weekends**: Data analyzed according to time, in one-hour blocks, between 12 a.m. and 12 a.m. (24 hours later) only for weekend days, independent of the day.

3.2 High Occupancy Channels

There were no high occupancy channels (HOCs)[5] detected in the 162–174 MHz band and 12 HOCs (representing 1.1 percent of channels) in the 406–420 MHz band.

Table 1. Total Number of Statistically Analyzed Channels Spaced 12.5 kHz Apart

Frequency band	Number of channels analyzed
162–174 MHz	943
406–420 MHz (including HOCs)	1112
406–420 MHz (excluding HOCs)	1100

[5] Section 5.4 of [2] provides a detailed description of HOCs.

3.3 Measurement Results

Figures 5 through 27 summarize the measurement results. For an explanation of how to interpret Figures 5 through 27, see [2]. As a quick reference, Tables 2 and 3 provide figure numbers for the 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 4.

Table 2. Figure Numbers for Graphs in the 162–174 MHz Band

Figure Number	5	6	7	8	9	10	11	12	13	14	15	A-1
Hourly Band Usage	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
Multiple Channelization Scenarios	x			x		x	x	x	x			
Multiple Time Scenarios			x									
Entire Week						x	x	x	x	x	x	
Date and Time of Day	x	x										x
Time for Any Day			x	x	x							
Weekdays			x									
Weekend Days			x									
All Channels	x	x	x	x	x	x	x	x	x	x	x	x
25-kHz Channelization	x			x		x	x	x	x			
12.5-kHz Channelization	x			x		x	x	x	x			

Table 3. Figure Numbers for Graphs in the 406–420 MHz Band

Figure Number	16	17	18	19	20	21	22	23	24	25	26	27	A-2
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
Multiple 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							
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			

Table 4. Minimum Threshold Values

Frequency band	dBm at measurement antenna terminals	dBμV/m field strength (0 dBi gain antenna)
162–174 MHz Band	-113	8
406–420 MHz Band	-119 [6]	10

Several of the channel-usage graphs show anomalies that require further explanation (the term anomaly refers to data that do not reflect what is truly occurring). As Figures 5 and A-1 show, there are three different times (on Monday afternoon, Tuesday morning, and Thursday morning) in which all data plots exceed 2.0 percent usage. Examining this data in greater detail revealed the presence of broadband, noise-like sources 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 of [2]. This conclusion was drawn by examining the data contained in Figures 6 and 9. Figure 6 shows large numbers of adjacent channels exhibiting their busiest hour to coincide with the presence of increased noise-like sources. As there are currently no licensed wide-band frequency allocations in either band, these usage anomalies cannot be attributed to them. This conclusion is reinforced by Figure 9 where a spike in usage occurs at the 2 p.m. hour from a noise-like source that exceeds the minimum threshold (-113 dBm), but not the next highest threshold (-110 dBm). As this data represents the mean usage across the entire measurement band, a large number of frequencies must have experienced the presence of a noise-like source at that hour.

In Figure 8, which shows the *Band Occupancy by Time-of-Day* plot, the same usage spike as noted above is visible. This usage spike would appear to be the time for the *Maximum Band Usage* value. However, this data is contaminated by the presence of a broadband, noise-like source, and although it is possible that the maximum usage does occur at 2 p.m., the results are inconclusive for that time period. For this reason, the maximum value at 2 p.m. is discarded in favor of the next-highest value occurring at 11 a.m. For amplitude probability distribution (APD) plots, time periods during which this noise-like source was present were excluded from analysis. To improve readability of the *Hourly Band Usage* plots, the noise-like source anomalies are often cut off by the top of the graphs, since this data is not relevant to analysis. As shown in Figure A-2, none of the anomalies that were manifested in the 162–174 MHz band 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 three different channelization schemes.

As described in Section 2.1 of [2], these schemes are referred to as: *All channels spaced 12.5 kHz apart*, *Old 25 kHz channelization*, and *New 12.5 kHz channelization*.

[6] For the Washington, DC measurements, the minimum threshold was -117 dBm. For the Denver measurements, the measurement system had been improved to give an additional 2 dB of dynamic range.

3.3.1 Results for 162–174 MHz Band

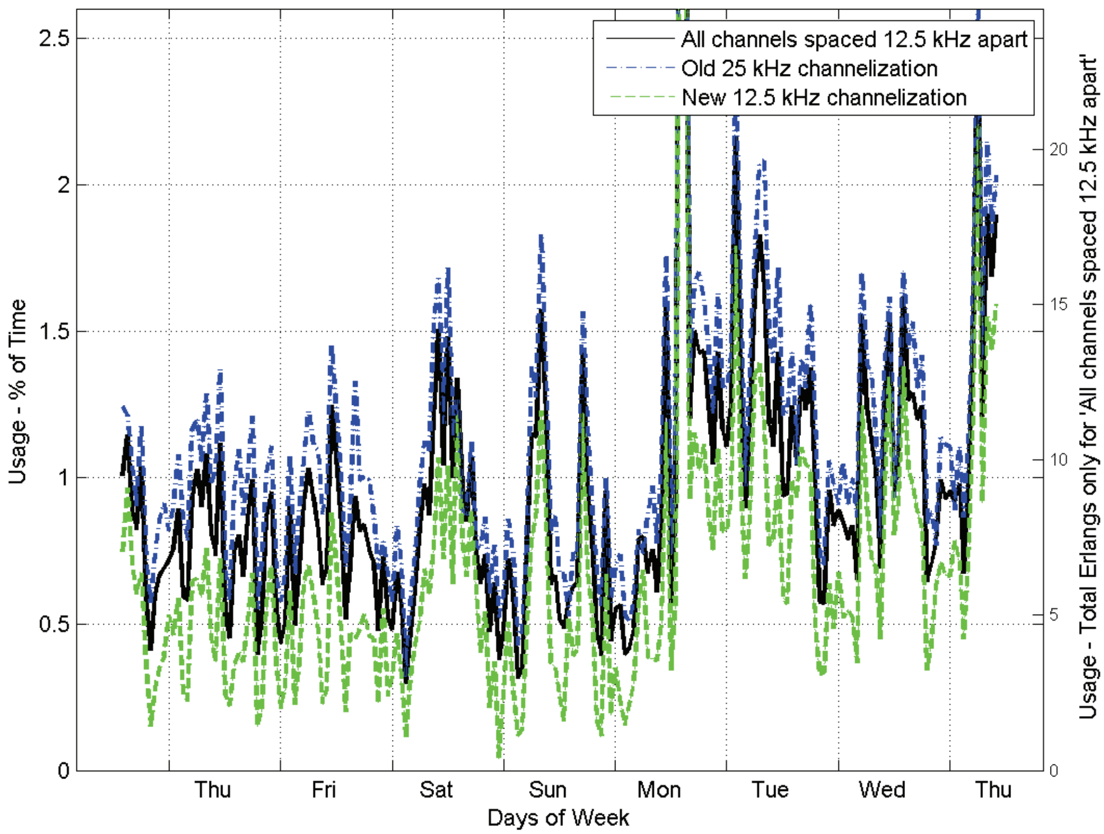

Figure 5. *Hourly Band Usage* (percent of time and total Erlangs) during the course of the measurements for the 162–174 MHz band (minimum threshold).[7]

[7] The large usage anomalies, exceeding 2.0 percent usage, occurring on Monday, Tuesday, and Thursday are due to external, noise-like sources received by the measurement system. Examining this data in greater detail revealed the presence of noise-like sources 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 of [2].

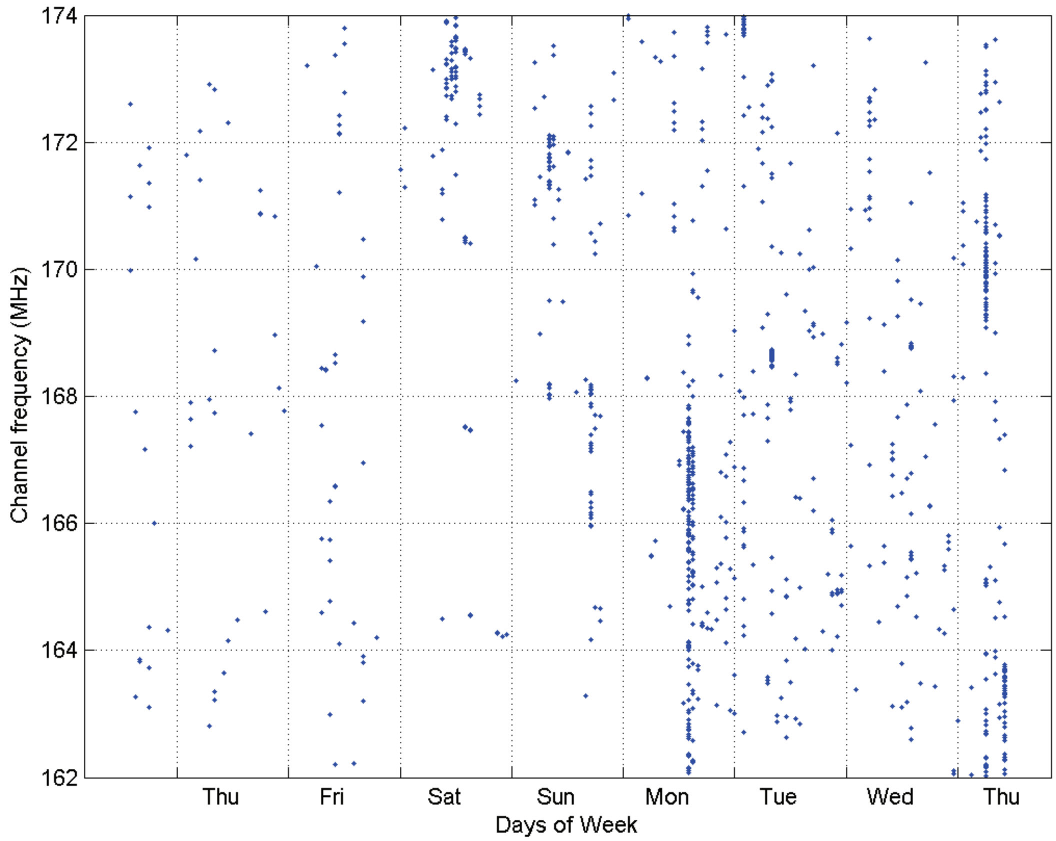

Figure 6. *Busiest Hour of the Week for Each Channel* in the 162–174 MHz band.

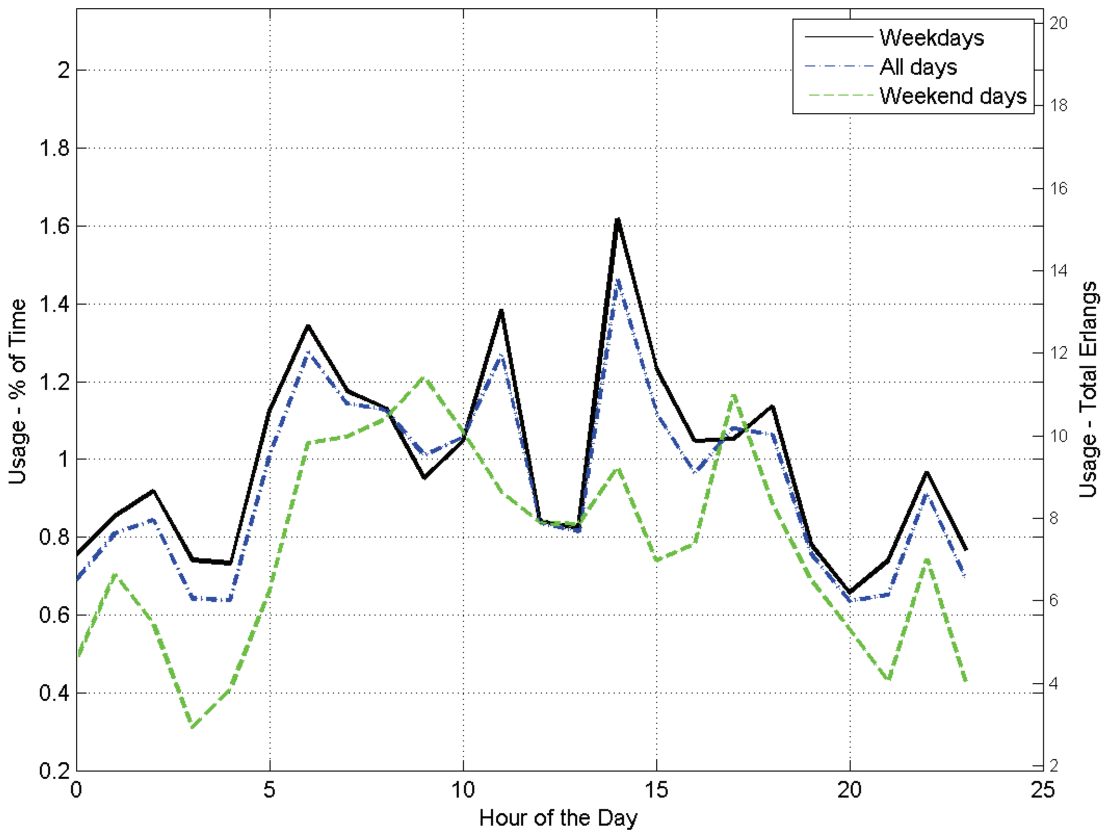

Figure 7. *Band Occupancy by Time-of-Day* (percent of time and total Erlangs) during different 24-hour time scenarios in the 162–174 MHz band (minimum threshold, all channels spaced 12.5 kHz apart).[8]

[8] In Figures 7, 8, and 9, there was a presence of a noise-like source around 2 p.m. (1400 hours) that evaded post-processing techniques. It is possible that the maximum usage does occur at 2 p.m., but, because the data is contaminated, no definitive conclusion can be reached about that specific measurement point for the minimum threshold.

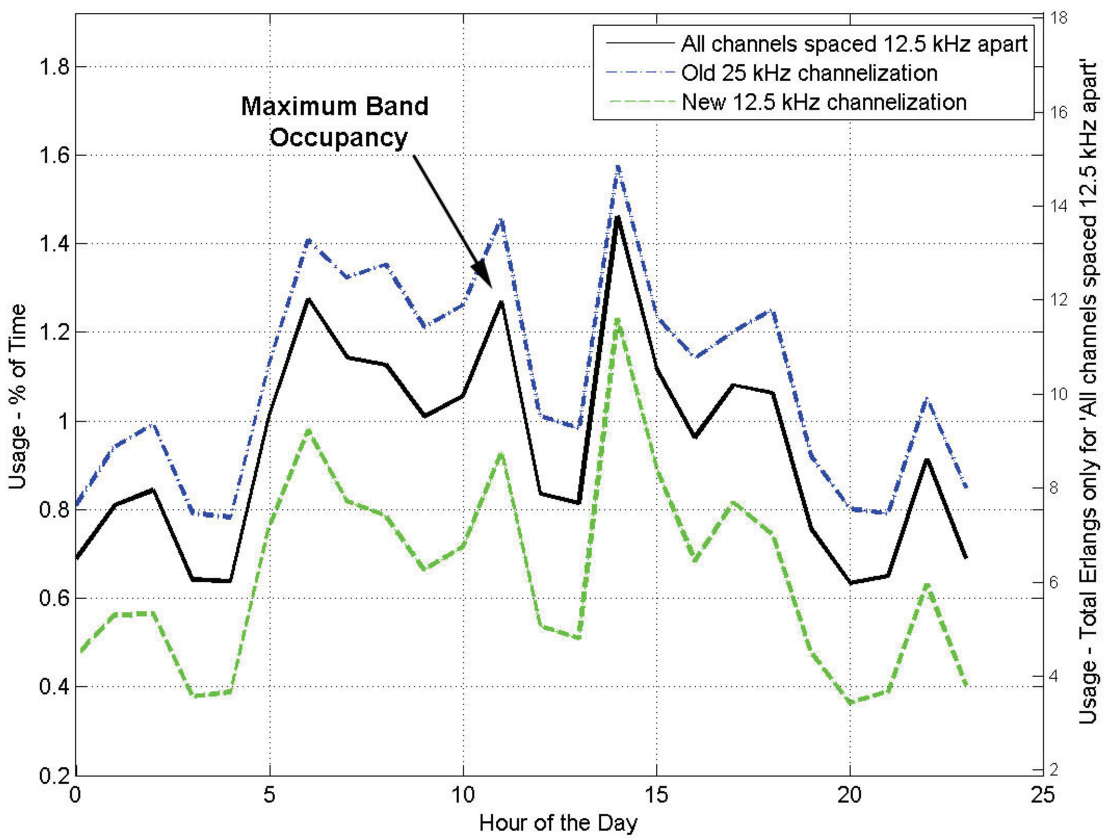

Figure 8. *Band Occupancy by Time-of-Day* (percent of time and total Erlangs) during the course of 24 hours, independent of the date, for different channelization scenarios in the 162–174 MHz band (minimum threshold).[9]

[9] As discussed in [2], the processed data in Figures 8 and 9 contain measurements on both Specific Location Assignments (base station has a fixed latitude and longitude location) and Area Assignments (base station is not constrained to a specific location) from the GMF database. The *Maximum Band Occupancy* in Figure 8, which includes both types of assignments, is about 1.3 percent at 11 a.m. 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.

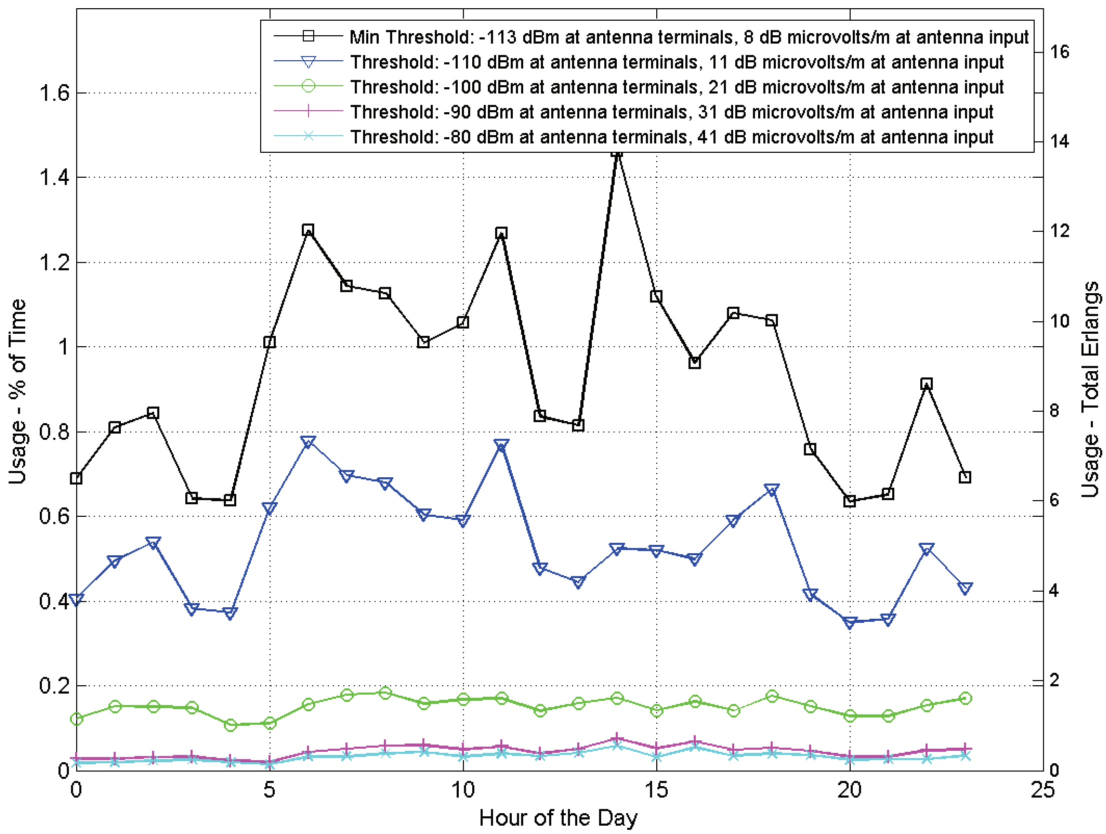

Figure 9. *Band Occupancy by Time-of-Day* (percent of time and total Erlangs) using different thresholds, independent of the date, for all 943 channels in the 162–174 MHz band.

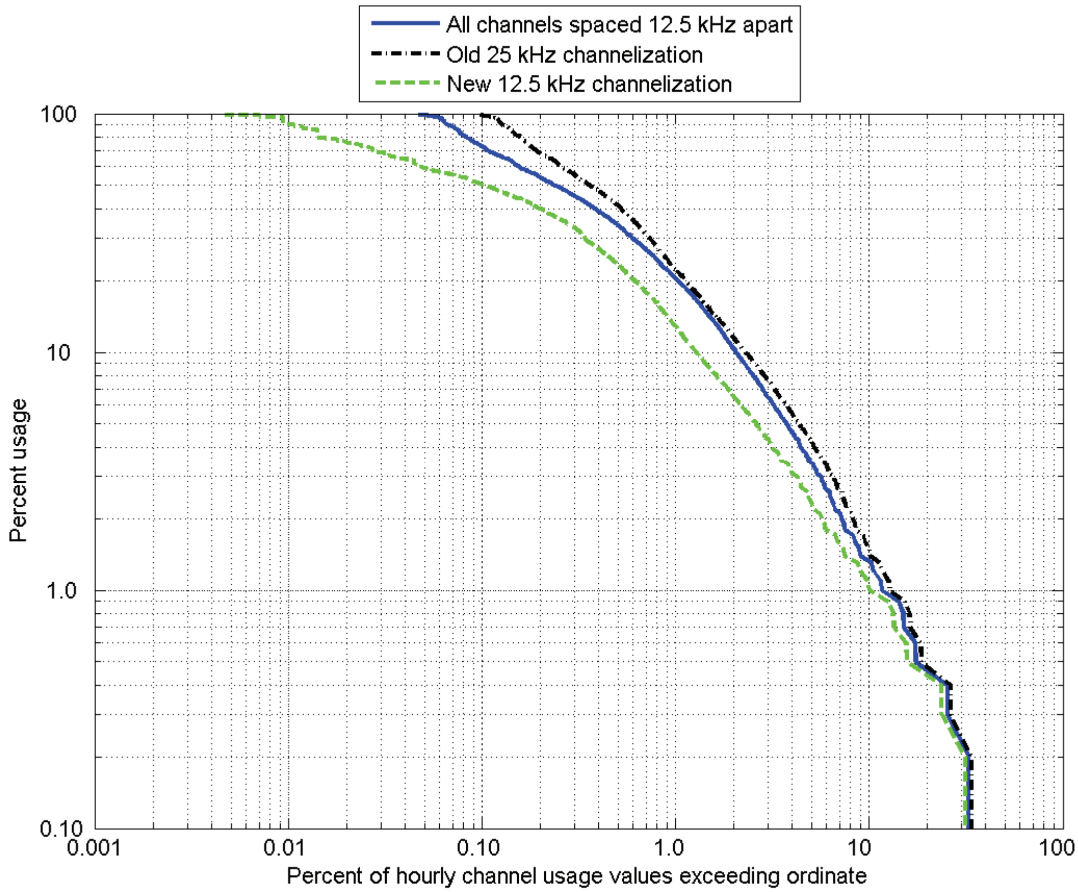

Figure 10. Percent of *Hourly Channel Percent Occupancy* values exceeding a given percent usage over the course of the measurements for the 162–174 MHz band (minimum threshold).

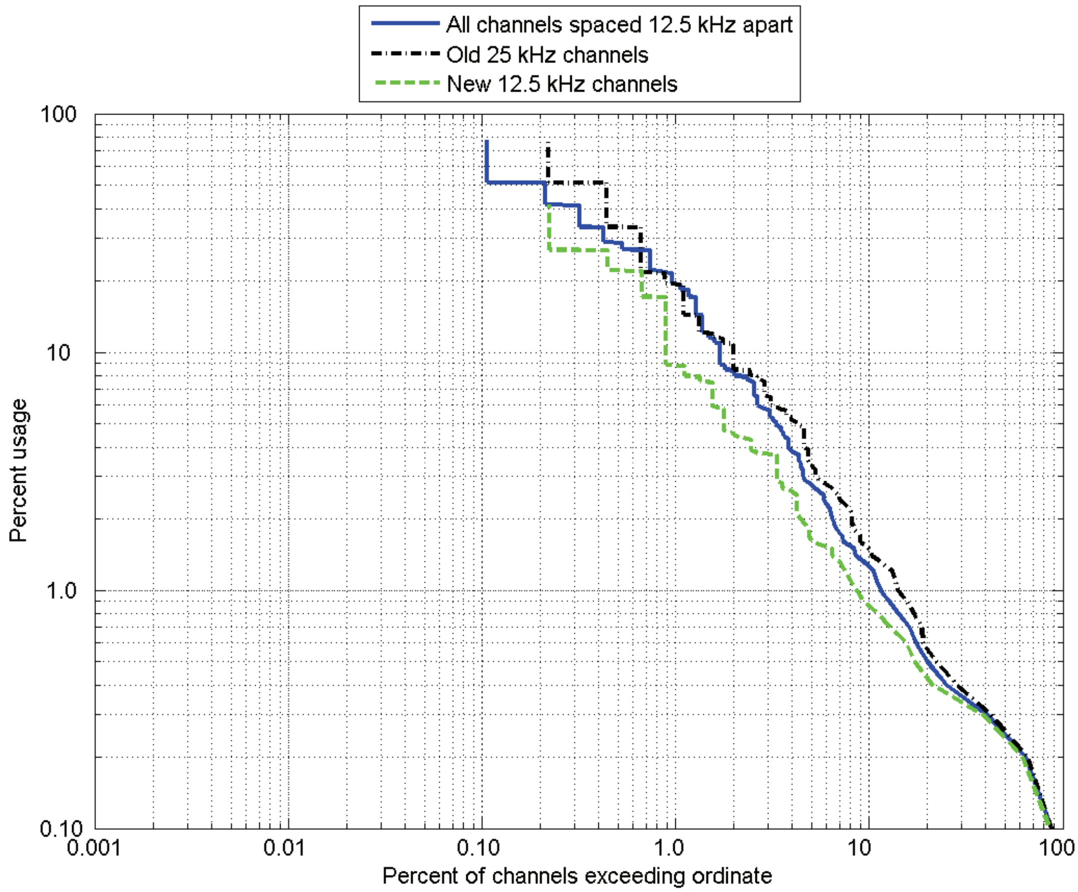

Figure 11. Percent of channels exceeding a given percent usage for *Channel Percent Occupancy* over the course of the measurements for the 162–174 MHz band (minimum threshold).

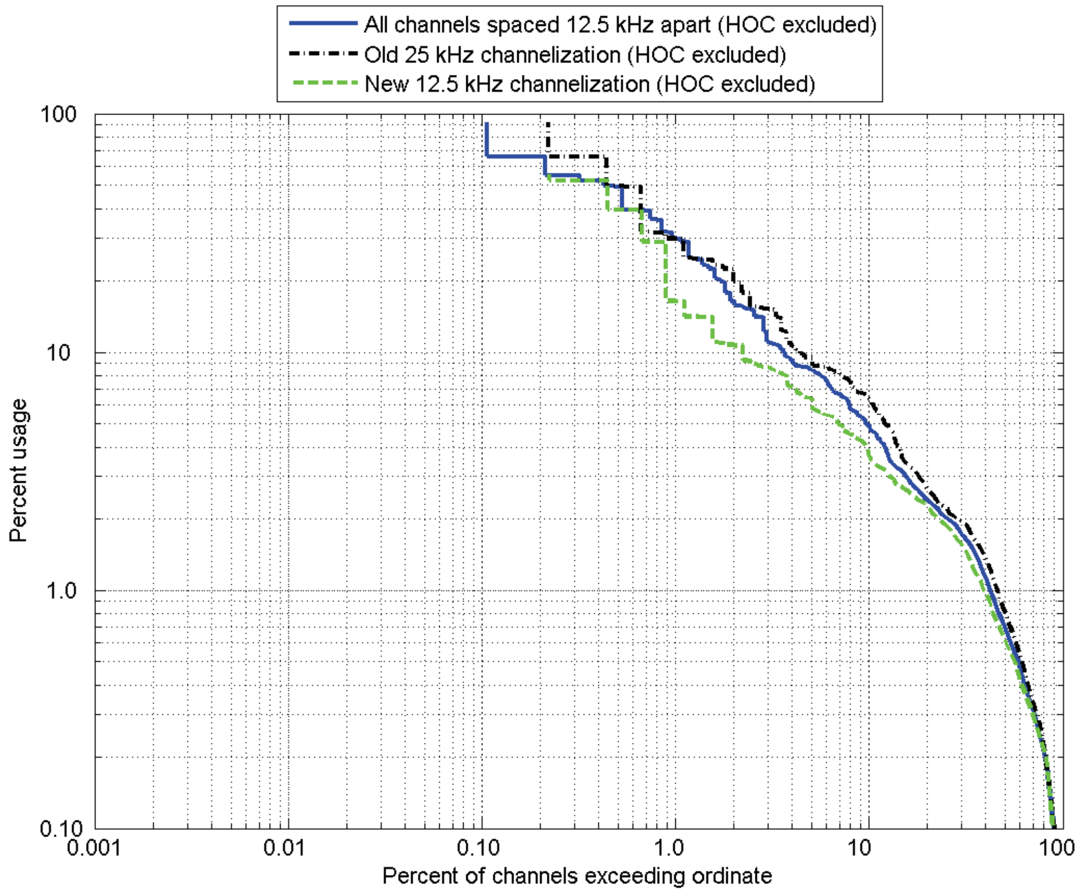

Figure 12. Percent of channels exceeding a given percent usage for the *Busiest Usage by Time-of-Day for Each Channel* during weekdays only in the 162–174 MHz band (minimum threshold).

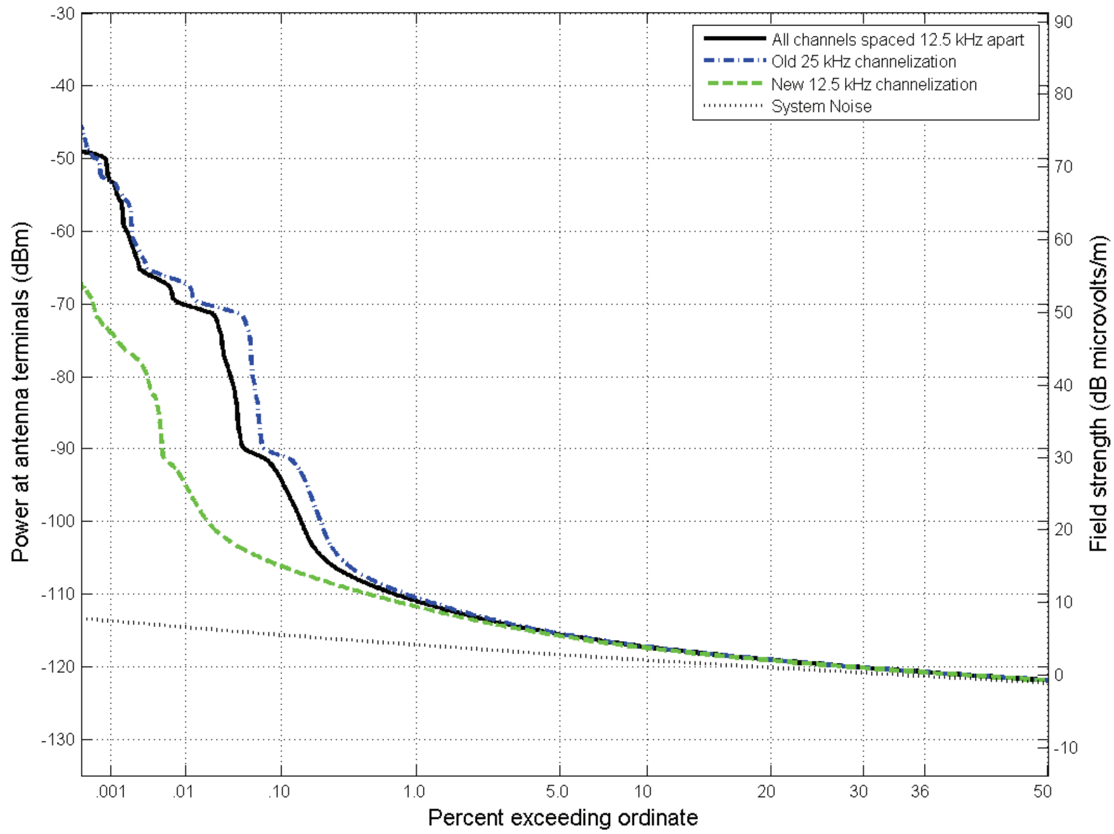

Figure 13. APDs of *Channel Power Values* for channels in the 162–174 MHz band — entire week, independent of date or time for different channelizations (minimum threshold).

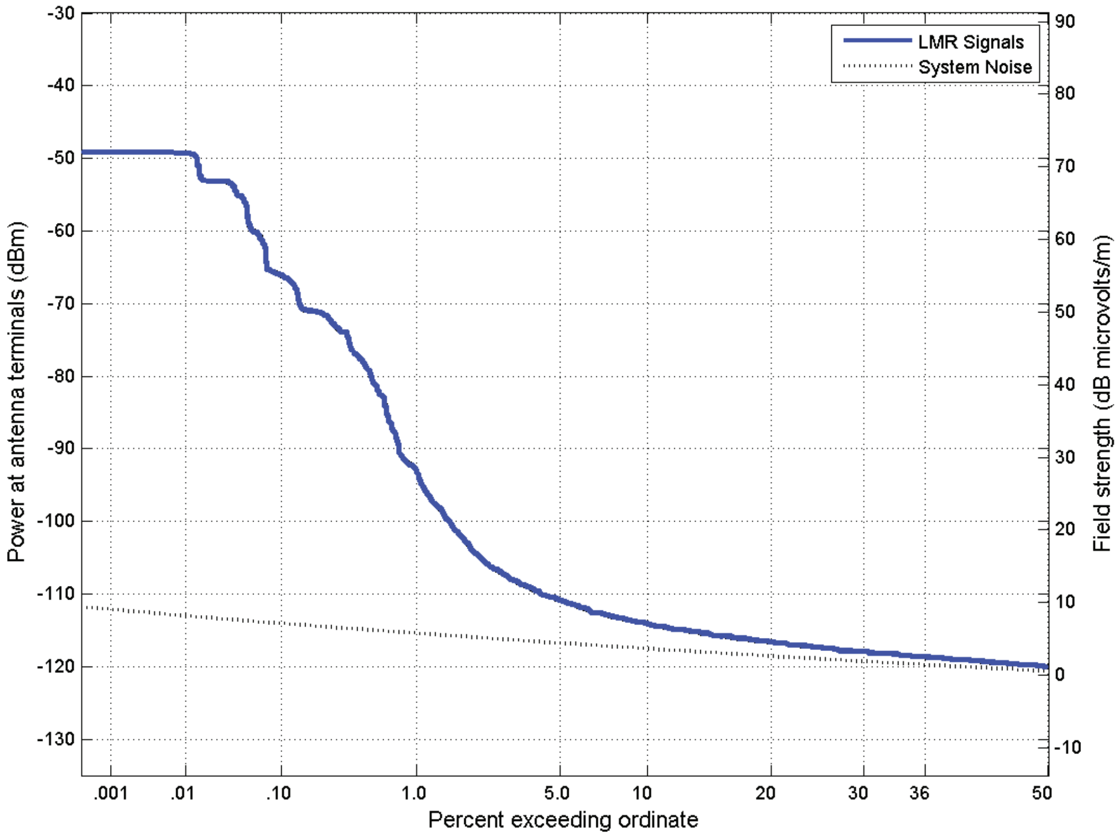

Figure 14. APDs of *Channel Power Values* for all channels spaced 12.5 kHz apart in the 162–174 MHz band for the busiest hour during the entire week independently for each frequency (minimum threshold).

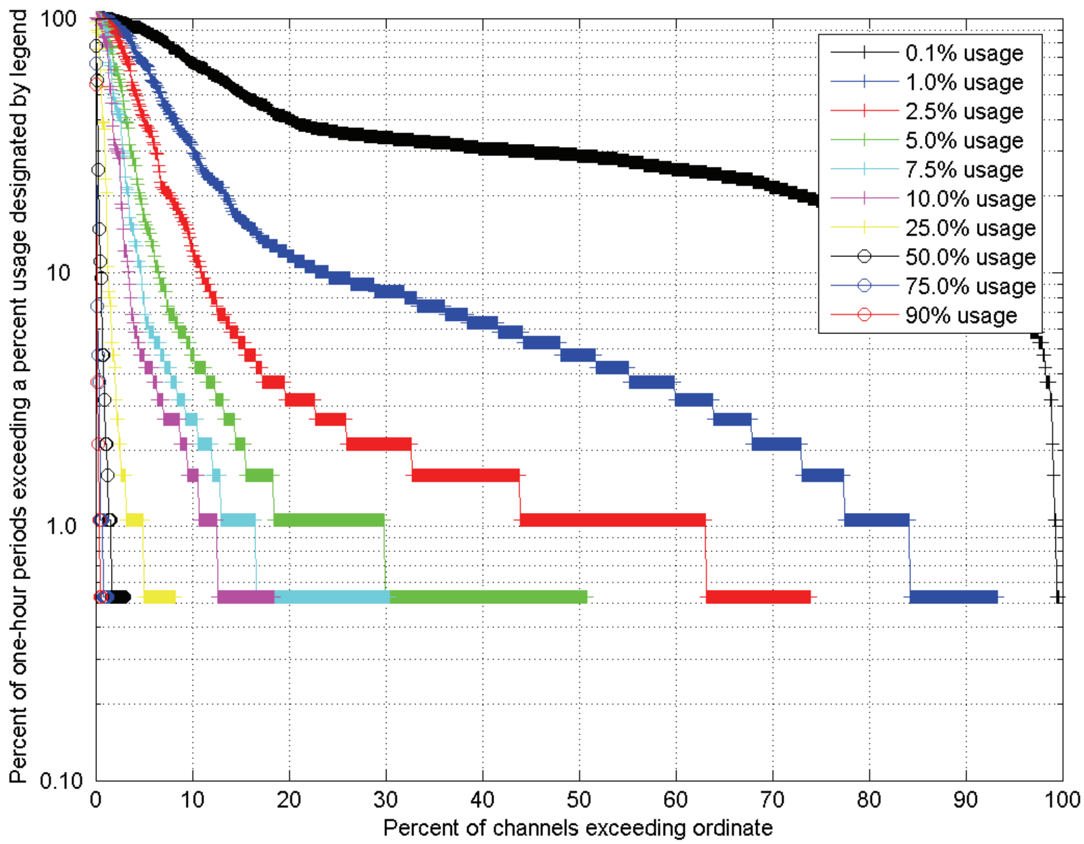

Figure 15. Cumulative distribution of the percent of channels that exceed a given percent of hours at greater than or equal to a given *Hourly Channel Percent Occupancy* (designated by legend) for all channels in the 162–174 MHz band (minimum threshold, entire week).[10]

[10] 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 188 hours of measurement during the course of the 8 days, a single one-hour time slot represents a "percent of hourly periods" of 0.53 percent, two hours represents approximately 1 percent, and three hours represents approximately 1.5 percent (consistent with the discrete steps seen in the figure above).

3.3.2 Results for 406–420 MHz Band

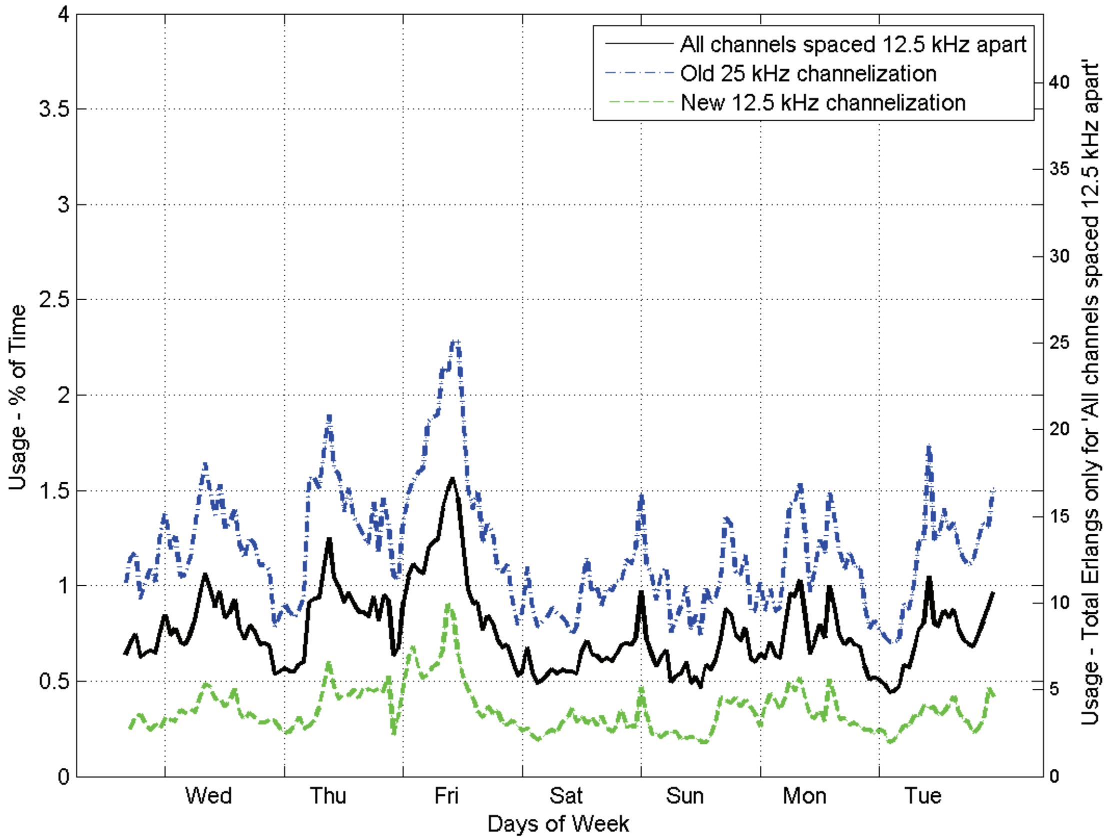

Figure 16. *Hourly Band Usage* (percent of time and total Erlangs) during the course of the measurements for the 406–420 MHz band (excluding HOCs; minimum threshold).

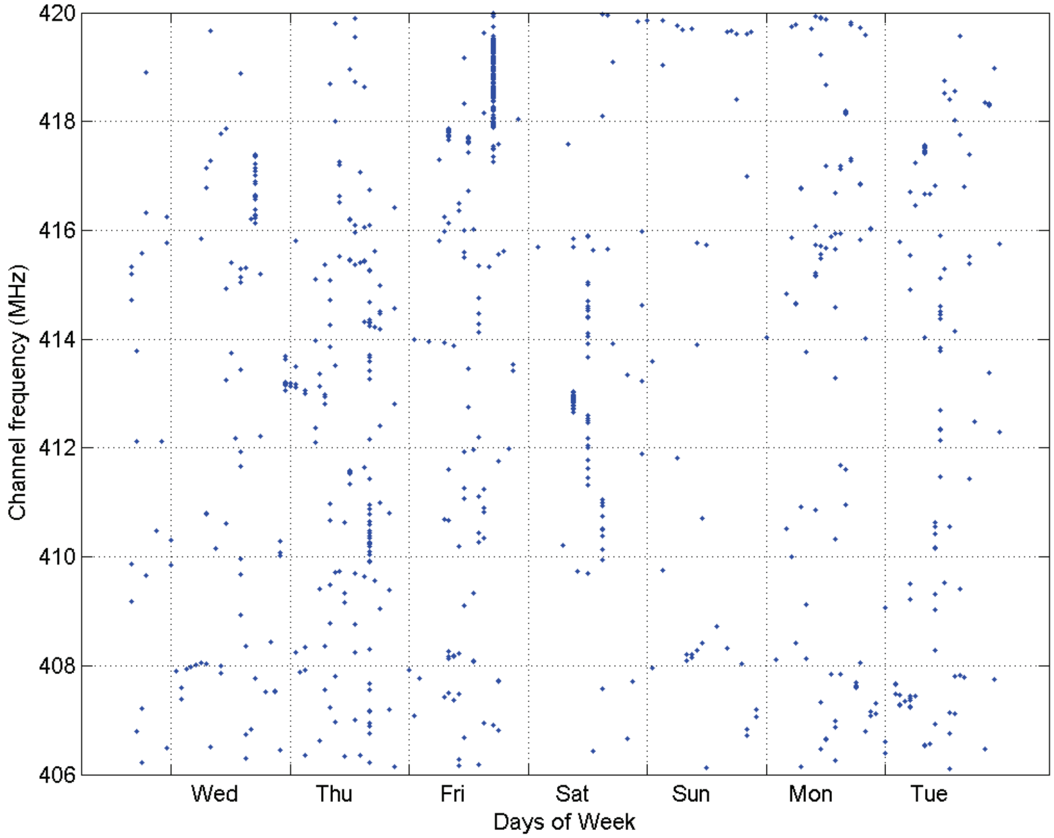

Figure 17. *Busiest Hour of the Week for Each Channel* in the 406–420 MHz band.

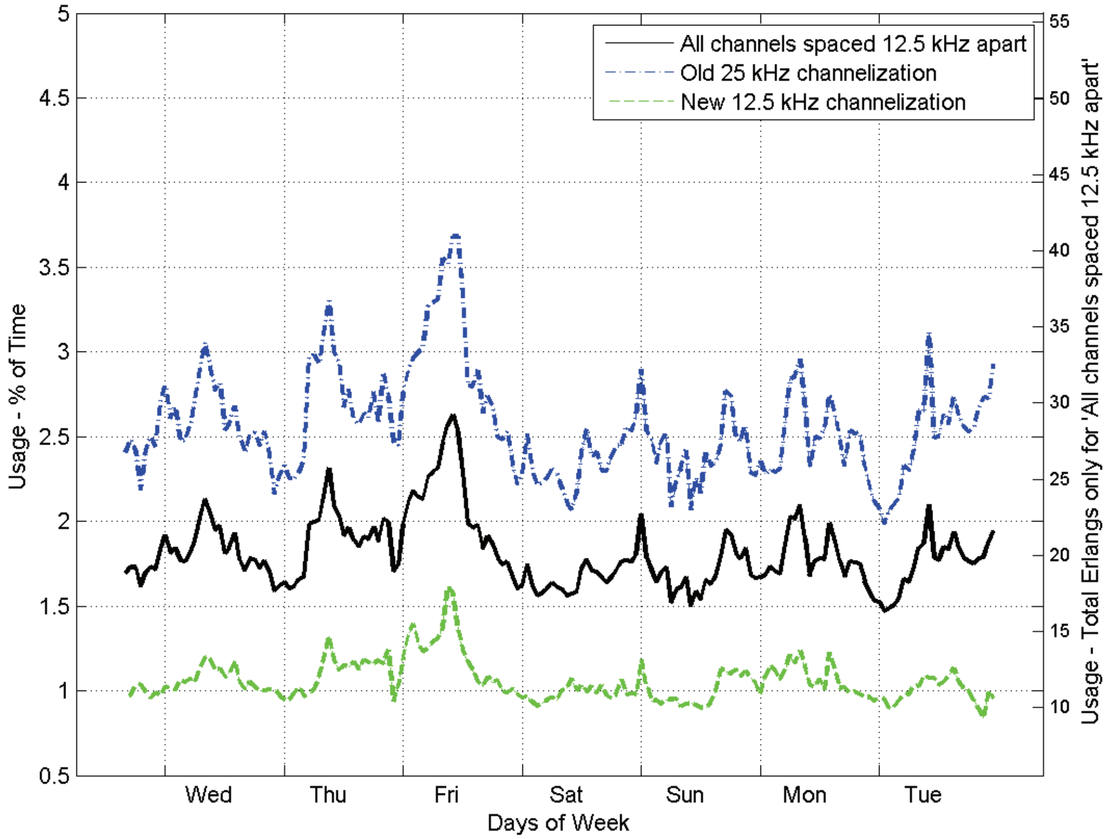

Figure 18. *Hourly Band Usage* (percent of time and total Erlangs) during the course of the measurements for the 406–420 MHz band (including HOCs; minimum threshold).

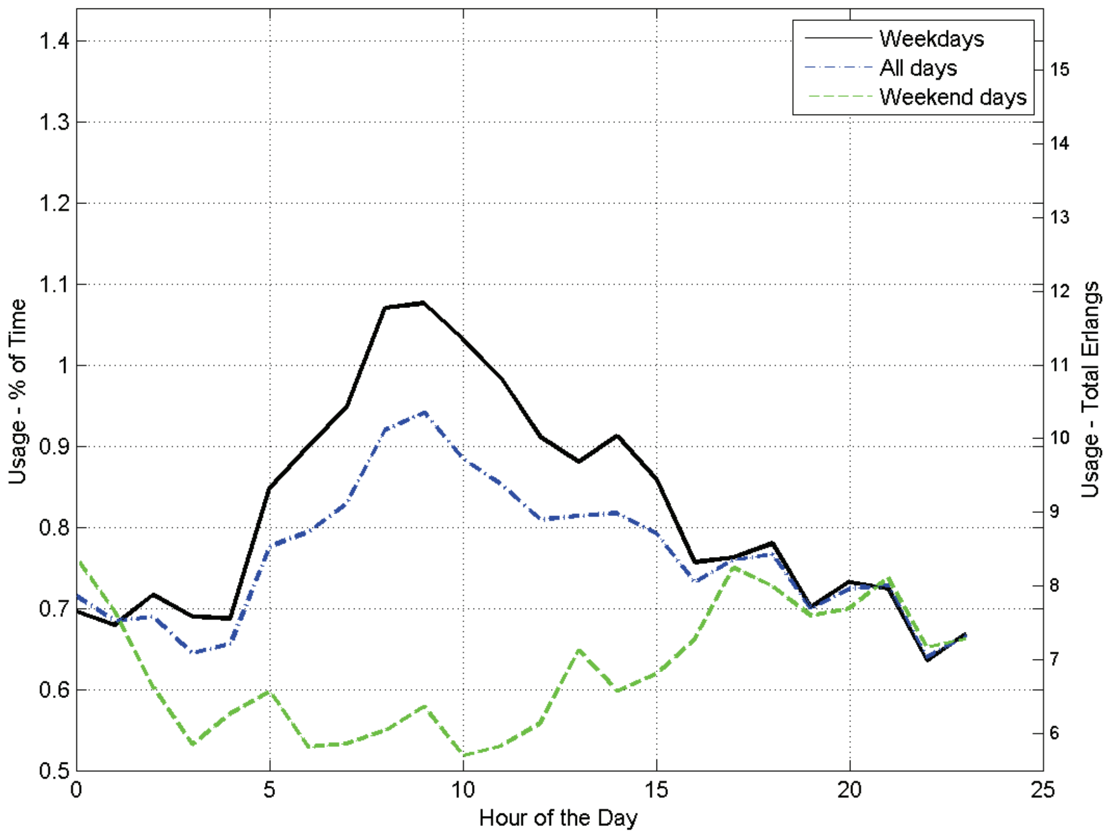

Figure 19. *Band Occupancy by Time-of-Day* during different 24-hour time scenarios in the 406–420 MHz band (excluding HOCs; minimum threshold).

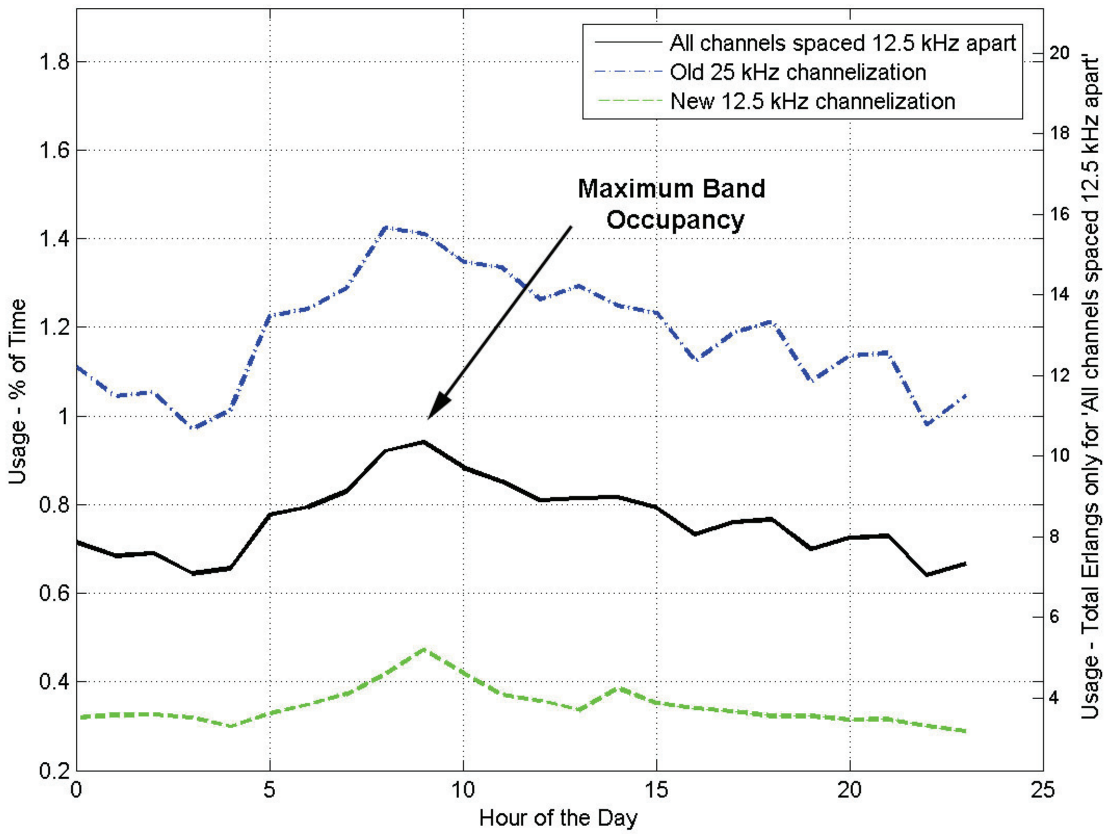

Figure 20. *Band Occupancy by Time-of-Day* (percent of time and total Erlangs) during the course of 24 hours, independent of the date, for different channelization scenarios in the 406–420 MHz band (excluding HOCs; minimum threshold).

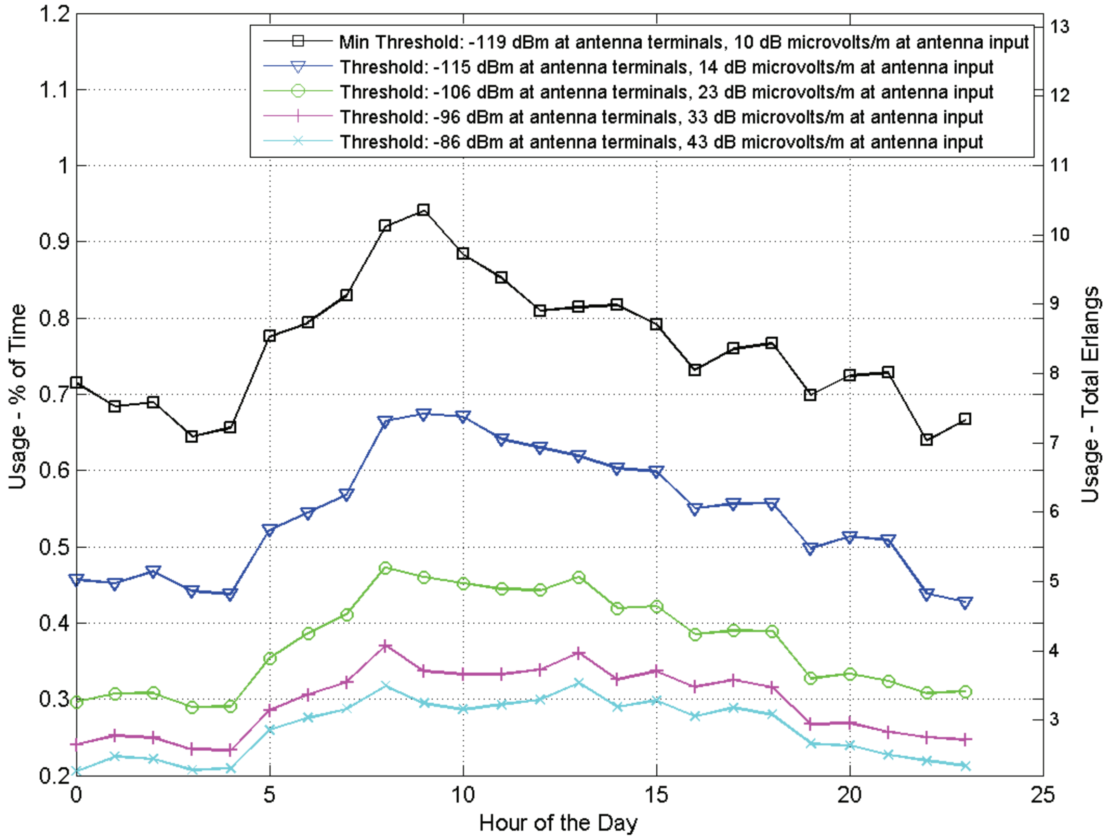

Figure 21. *Band Occupancy by Time-of-Day* (percent of time and total Erlangs) using different thresholds, independent of the date, for all 1,100 channels in the 406–420 MHz band (excluding HOCs).

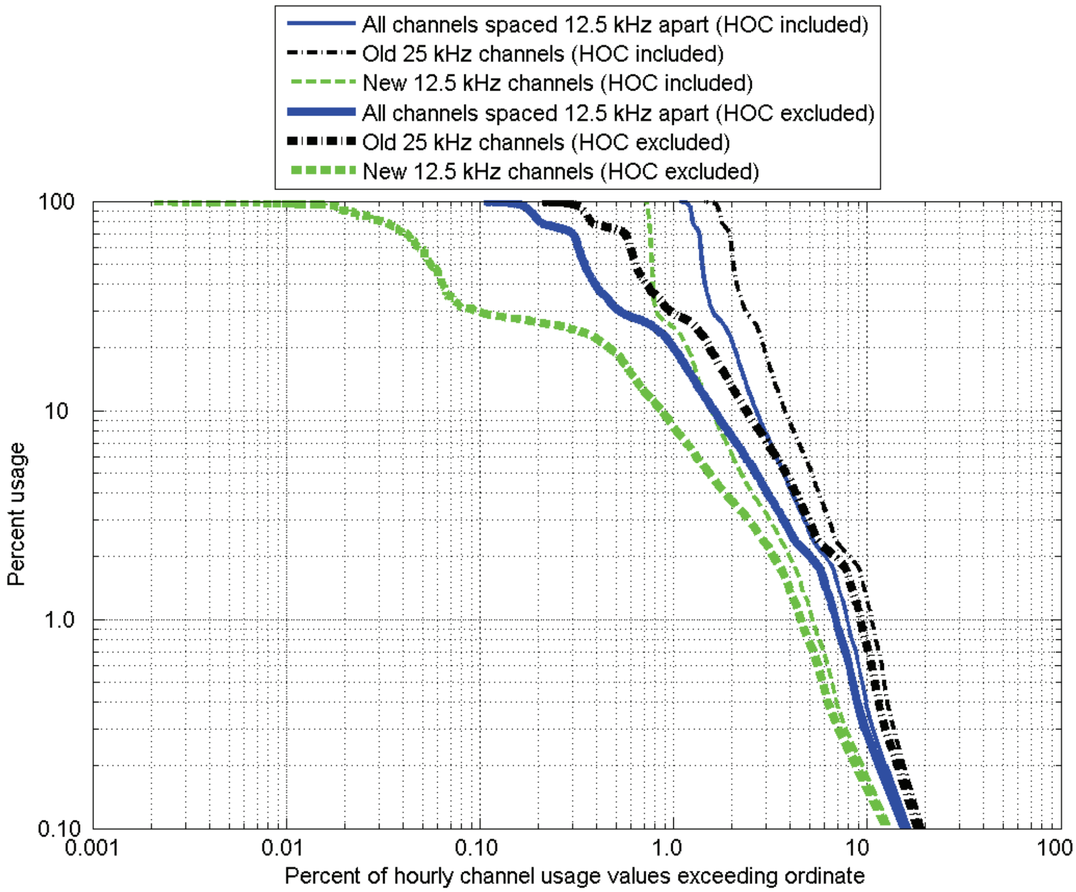

Figure 22. Percent of *Hourly Channel Percent Occupancy* values exceeding a given percent usage over the course of the measurements for the 406–420 MHz band (minimum threshold).

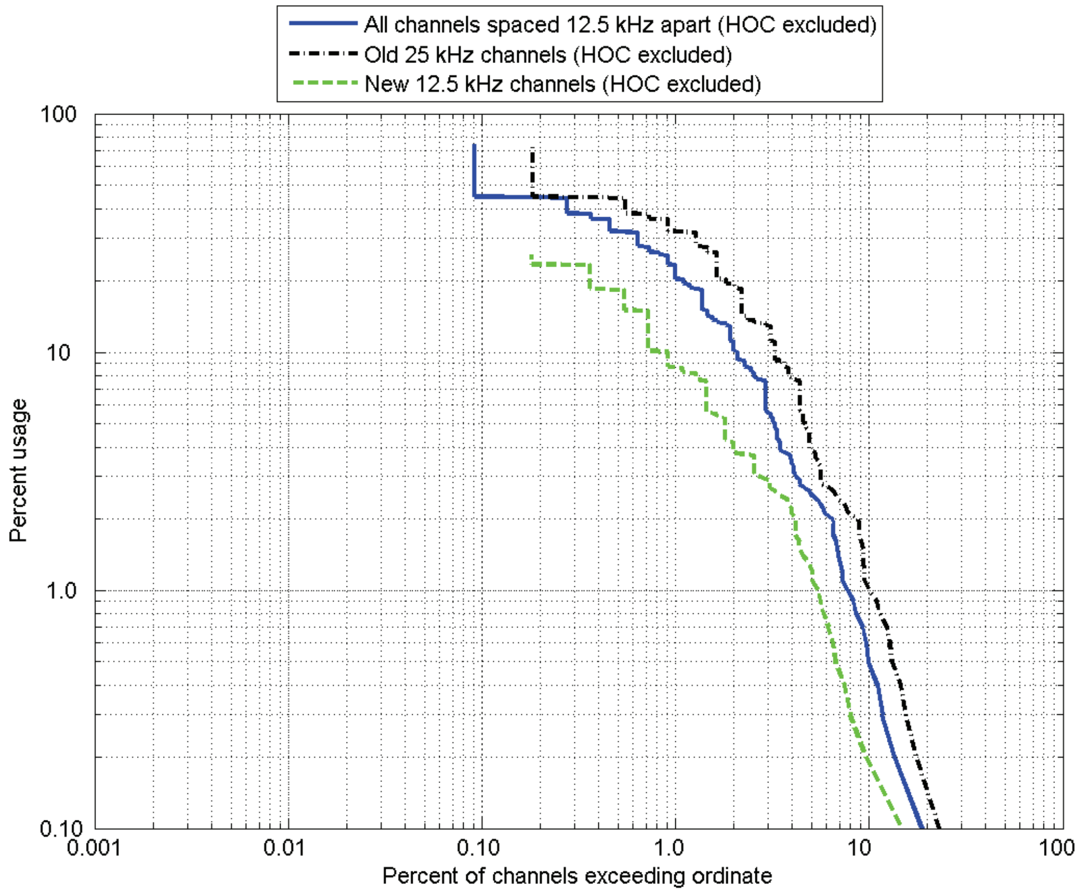

Figure 23. Percent of channels exceeding a given percent usage for *Channel Percent Occupancy* over the course of the measurements for the 406–420 MHz band (minimum threshold).

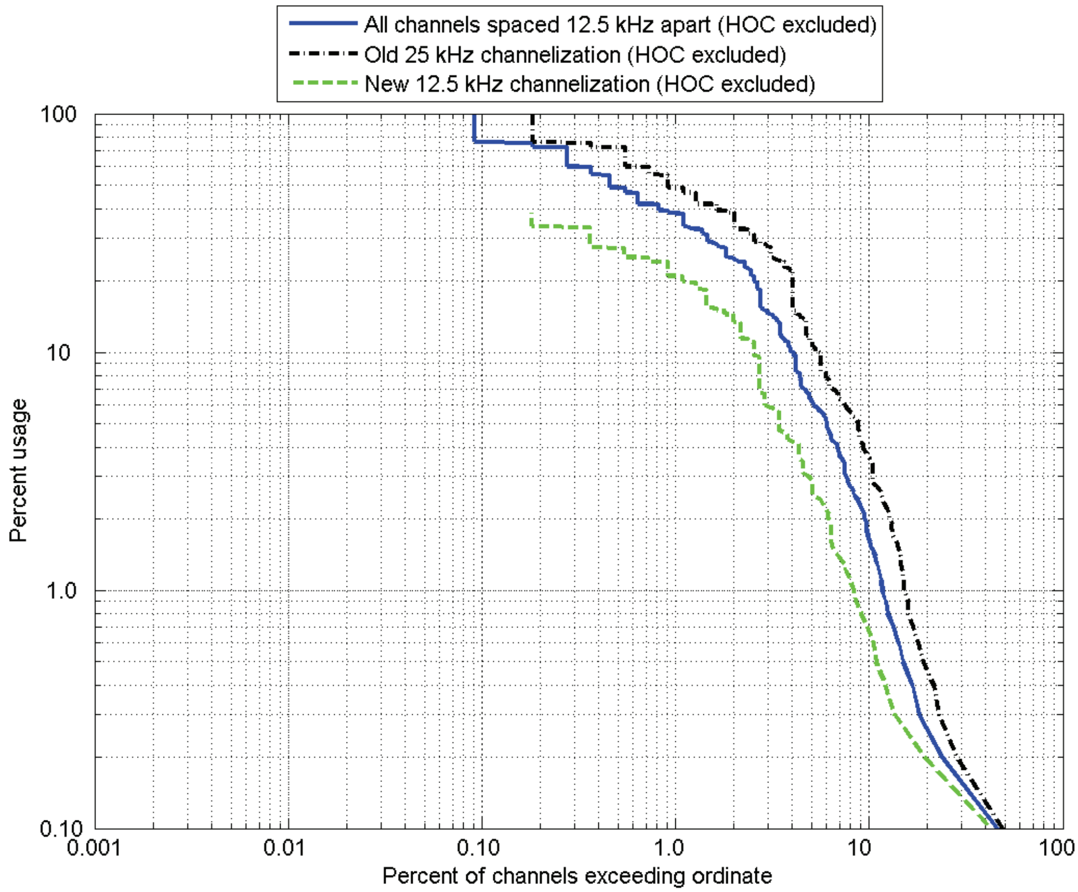

Figure 24. Percent of channels exceeding a given percent usage for the *Busiest Usage by Time-of-Day for Each Channel* during weekdays only in the 406–420 MHz band (minimum threshold).

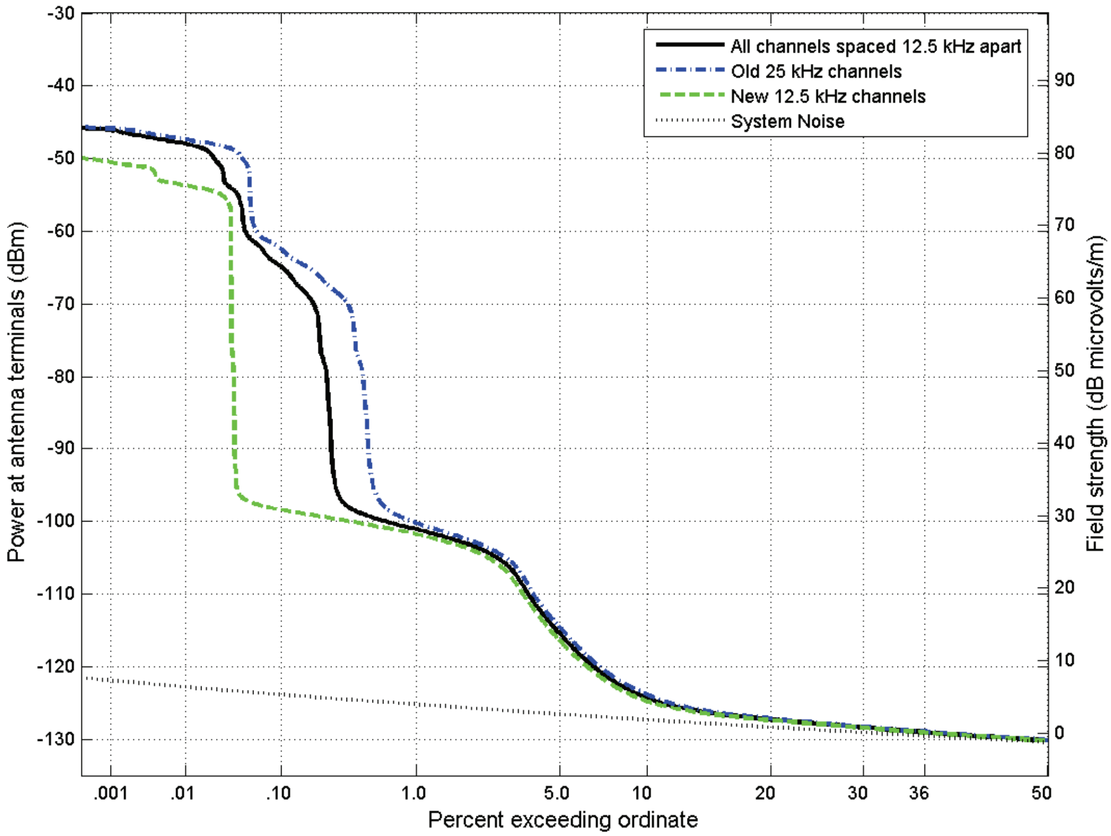

Figure 25. APDs of *Channel Power Values* for channels in the 406–420 MHz band — entire week, independent of date or time for different channelizations (excluding HOCs; minimum threshold).

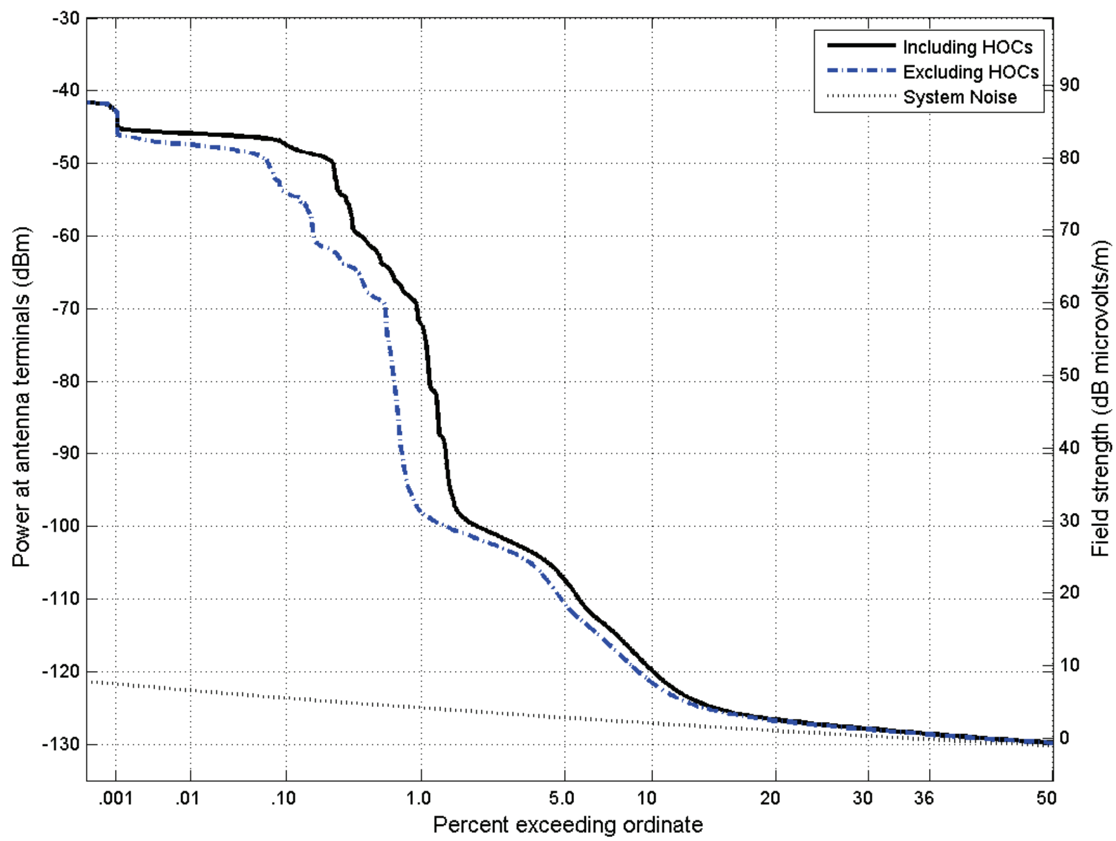

Figure 26. APDs of *Channel Power Values* for all channels spaced 12.5 kHz apart in the 406–420 MHz band for the busiest hour during the entire week, independently for each frequency for different HOC scenarios (minimum threshold).

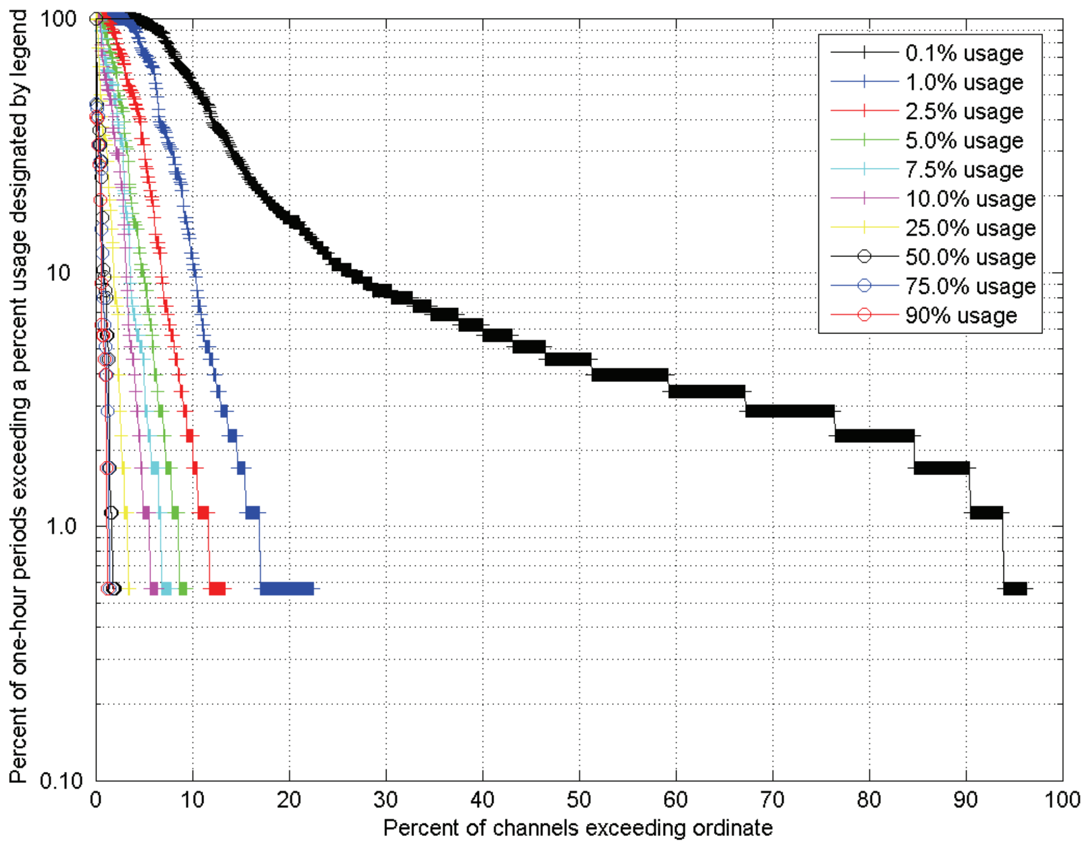

Figure 27. Cumulative distribution of the percent of channels that exceed a given percent of hours at greater than or equal to a given *Hourly Channel Percent Occupancy* (designated by legend) for all channels in the 406–420 MHz band (excluding HOCs; minimum threshold).

4 SUMMARY

The measured data presented in this report characterize channel usage of LMR systems operating in the 162–174 and 406–420 MHz frequency bands in the Denver metropolitan area. The analysis of the data is used to present the percent usage for a typical or representative channel during an 8-day measurement period (October 26 to November 3, 2005) using sampling procedures for the measurements.

A summary of the measurement results for channel usage and diurnal patterns for each band is given in Sections 4.1 through 4.2. There are several limitations to the measurements, however, that need to be considered.

Because the measurement system coverage area for mobile and portable stations is not as extensive as for base stations and repeaters, and because terrain and structural obstruction may prevent adequate reception of these mobile radio signals by the measurement system, the usage statistics may not fully reflect the actual usage within the bands. However, for each transmission by a portable or mobile station there is usually a corresponding transmission response from a base station or repeater that reflects that usage. Therefore, for the worst case, where no portable and mobile station transmissions are detected, the measured base station usage would need to be doubled (assuming no talk-around). In reality, the usage statistics lie somewhere in between these two extremes, since some signals from mobile and portable stations were detected by the measurement system. It is also possible that the measurement system coverage area for base stations is extensive enough to detect frequency reuse, thus reflecting a higher than expected average usage.

There are some assignments that, while included in the overall statistical analysis, are not used for LMR transmissions, such as hydrology channels. Other assignments cannot be detected for reasons described in the previous paragraph. The received power from some assignments may be below the measurement system's sensitivity and, therefore, not detected. Some channels may be assigned for "listening only" in the sense that they infrequently carry traffic but are monitored continually for emergency transmissions. In every case, the result is that the usage statistics may show less usage than would be expected if the analysis were performed only on channels that are reserved for transmission and can be detected within the measurement receiver coverage. Furthermore, any 12.5-kHz channel that has a wideband assignment adjacent to it generally cannot be used within the measurement system coverage area and therefore, would not show any activity.

Out of the 36 hydrology channels (see Definitions) in the 162–174 MHz band and the 12 hydrology channels in the 406–420 MHz band, none exceeded 80 percent usage (some displayed very little, if any, usage), so all were included in the overall LMR occupancy statistics. Upon closer examination, it was determined that the hydrology channels in the 162–174 MHz band had a mean usage of 1.2 percent and the hydrology channels in the 406–420 MHz band had a mean usage of 0.0 percent. For the 162–174 MHz band, the inclusion of hydrology channels increased the mean usage by 0.03 percent, and for the 406–420 MHz band, the inclusion of hydrology channels decreased the mean usage by 0.01 percent.

While every effort was made to minimize the effects of interference from noise-like sources, as described in Section 4.1 of [2], there were occasional periods when broadband, noise-like sources raised the power in the entire band enough for individual channels to exceed the detection threshold, but not enough to be identified as corrupted data and discarded from the analysis. It is difficult to determine precisely how often this occurred, but it may have occurred enough to skew the mean usage values somewhat towards higher than expected usage values.

Much of the data in this report is presented 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 12, there are a few channels with relatively high usage (20 percent of the channels with greater than 2.3 percent usage), but far more channels with relatively low usage (30 percent between 0.5 to 1.6 percent and 40 percent less than 0.5 percent), the mean is skewed, due to outliers, towards a larger value than what one might think of as “typical.” In this case, the median may be more representative of a “typical” channel usage and can be extracted from the cumulative distribution plots in Figures 10, 11, and 12 (detailed analysis of the plots is described in Section 5.6 of [2]).

Because most of the channels in these bands are statically assigned to networks or individual users, 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. It also should be noted that agencies may have channel usage that deviates from these values. Likewise, none of these measurements were made during a major emergency that might have greatly increased a channel’s use.

The channel occupancy measurements in this report can be used for specifying the overall performance objectives of a hypothetical communications system using a different technology (e.g., trunking). By designing the hypothetical system to provide the same overall communications capability as the existing LMR systems, the existing and hypothetical systems could then be compared to examine relative total spectrum usage (number of channels required for each system). For example, [4] used channel occupancy measurements from the Washington DC metropolitan area [2], along with the GMF data from [5], to design and assess several hypothetical trunked LMR systems, and compared their spectrum usage to conventional systems in the same area. [11]

The intent of the measurements was not to examine details of performance and use for the characterization of individual channels, but rather, for the channels in aggregate. This individual channel information, as well as more extensive measurements, may be required for a detailed engineering design for a next generation system.

4.1 Overall Results

Hourly Band Usage within the measurement system coverage area varies between 0.3–1.6 percent (Figures 5 and 16) for the two measured bands, but shows the busiest hours are between

[11] Reference [4] assesses several hypothetical LMR system designs and develops a comparison of the spectrum resources used by alternative trunked LMR system designs and conventional LMR systems. Reference [5] analyzes Federal frequency assignment data to assess the geographic coverage of existing conventional LMR systems.

7 a.m. and 5 p.m., with the minimum usage near midnight. Results also show that the newly created 12.5-kHz channels are not yet used as much as the old 25-kHz channels. Note that these are average statistics, and usage for individual channels by agencies may deviate significantly from the overall band usage.

4.1.1 Results for 162–174 MHz band

For a mean[12] detection threshold of -113 dBm in the 162–174 MHz band, *Band Occupancy by Time-of-Day* within the measurement system coverage area is between 0.6–1.5 percent for all channels spaced 12.5 kHz apart, 0.8–1.6 percent for the old 25-kHz channels, and 0.4–1.2 percent for the new 12.5-kHz channels (Figure 8). The highest conclusive value of the *Band Occupancy by Time-of-Day* represents the *Maximum Band Occupancy*, which is 1.3 percent for all channels spaced 12.5 kHz apart and includes both Specific Location and Area frequency assignments. Note that the *Maximum Band Occupancy* does not occur at the 2 p.m. hour, which is shown in Figure 8 to have the highest usage (1.5 percent) since the data at that hour was contaminated by an external noise-like source and is suspect. Instead, the 1.3 percent value occurring at the 11 a.m. hour was selected. When the *Maximum Band Occupancy* for channels spaced 12.5 kHz apart is calculated based on only the Specific Location Assignments, the value is 1.9 percent.[13]

The *Band Occupancy by Time-of-Day* for conventional LMR systems can be compared to allowable call-blockage (typically referred to as Grade of Service) as recommended in the Final Report of the PSWAC [3]. In that report the committee recommends that blockage 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 systems where channels are assigned statically. Since the systems measured in the 162–174 MHz band are conventional systems, the measured usage during the busiest hour of 1.3 percent is relatively consistent with the recommendations by the PSWAC.

For a mean detection threshold of -113 dBm, the overall *Percent Band Usage* for the 162–174 MHz band during weekdays is 0.99 percent over a 24-hour period, 1.12 percent between 8 a.m. and 5 p.m., and 2.25 percent for the *Average of Busiest Usage by Hour* (Table A-2). For *Busiest Usage by Time-of-Day*, 40 percent of the channels exceed a usage of 1 percent, while 10 percent of the channels exceed 5 percent, and 1 percent of the channels exceed 30 percent (Figure 12).

[12] Because the detection threshold, especially for the minimum threshold, is not constant across the frequency channels, threshold values given for statistical analysis are stated in terms of “mean” threshold power.

[13] The Specific Location Assignments, as researched by OSM, refer to the frequency assignments in the GMF for LMR base stations that have a fixed latitude and longitude location. The other frequency assignments in the GMF are the Area Assignments that have base stations not constrained to a specific location.

4.1.2 Results for 406–420 MHz band

For a mean detection threshold of -119 dBm in the 406–420 MHz band (HOCs excluded), *Band Occupancy by Time-of-Day* within the measurement system coverage area varies between 0.65–0.95 percent for all channels spaced 12.5 kHz apart, 0.95–1.45 percent for the old 25-kHz channels, and 0.30–0.45 percent for the new 12.5-kHz channels (Figure 20). The highest conclusive value of the *Band Occupancy by Time-of-Day* represents the *Maximum Band Occupancy,* which is 0.95 percent for all channels spaced 12.5 kHz apart.

For a mean threshold level of -119 dBm, overall *Percent Band Usage* for the 406–420 MHz band during weekdays is 0.82 percent over a 24-hour period, 0.94 percent between 8 a.m. and 5 p.m., and 1.53 percent for the *Average of Busiest Usage by Hour* (Table A-5). For *Busiest Usage by Time-of-Day*, 12 percent of the channels exceed 1 percent, while 10 percent of the channels exceed 2 percent, and 1 percent of the channels exceed 40 percent (Figure 24).

4.2 Diurnal Patterns for Both Bands

In the 162–174 MHz band, the diurnal behavior was similar, irrespective of whether they were measured for all days, weekdays or weekends. The highest overall usage occurred on weekdays (Figure 7), with the normal daylight hours showing the most activity. Curiously, there was a duration of time in the mid-morning hours where the weekend use dominated the weekday use.

In the 406–420 MHz band, a distinct difference in diurnal pattern can be noted between the weekday and weekend cases (Figure 19), with the usage being higher during normal daylight hours on the weekdays and outside of normal daylight hours on weekends. Usage on the weekends is decreased by a factor of as much as 2 during normal daylight hours when compared to weekdays. There was a small duration of time in the early morning hours where usage was higher for the weekend case when compared to the weekday case.

When examining the *Busiest Hour of the Week for Each Channel*, the busiest hours are more broadly grouped in the daytime hours (Figures 6 and 17). There are a few occurrences where blocks of adjacent frequencies appear to have the busiest hour all at the same time. However, such occurrences are not typical. Based on our data, we conjecture that whenever large numbers of adjacent frequencies appear to become busy at the same time, there is a possibility that the measurements were affected by broadband noise-like RF energy.

4.3 Evaluation of Measurement Techniques and Technologies

ITS developed custom hardware and software to make LMR channel occupancy measurements for the bands 162–174 and 406–420 MHz in the Washington, DC and Denver metropolitan areas. The measurement techniques and equipment described in [2] can be used to perform future LMR measurements at other locations. To improve the techniques, future LMR measurements will have more sampling time per channel and remove hydrology channels from the post processing. At the same time, future post processing techniques should provide the ability to gain access to mid-level calculations or steps and permit the viewing of intermediate results.

5 ACKNOWLEDGEMENTS

This project involved technical contributions by various individuals at the Institute for Telecommunication Sciences. The authors recognize Dr. William Kissick for his vision and leadership, Brent Bedford for his technical and theoretical support, Iris Tobias for her support, Yeh Lo for his work on the preselectors as well as other system development, Rick Statz and Steve Engelking for software development, and Margaret Luebs for editorial review.

The authors also wish to recognize Ed Drocella, Robert Sole, Bernard Joiner, Gary Patrick, Kim Cai, Yang Wang, and Dave Anderson from OSM for their support.

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[2] J.R. Hoffman, R.J. Matheson, and R.A. Dalke, "Measurements to characterize land mobile channel occupancy for Federal bands 162–174 MHz and 406–420 MHz in the Washington, D.C., area," NTIA Report 07-448, Jul. 2007, Available: <http://www.its.bldrdoc.gov/pub/ntia-rpt/07-448/>.

[3] Public Safety Wireless Advisory Committee (PSWAC) Report, Spectrum Requirements Subcommittee (SRSC) Final Report, Volume 2, Appendix D, Page 76, Sept. 1996.

[4] K. Cai, B. Joiner, R.J. Matheson, E. Drocella, G. Patrick, D. Anderson, "Assessment Of alternative future Federal land mobile radio systems," NTIA Report 08-451, Dec. 2007, Available: <http://www.ntia.doc.gov/osmhome/reports.html>.

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APPENDIX A: SUPPLEMENTAL MEASUREMENT RESULTS

This appendix provides additional results of usage at each hour for different thresholds and tables summarizing average usage. For an explanation of how to interpret these additional results, see Section 5.6 of [2], specifically pages 34, 35, and 44. The first section shows, for the purpose of discussing anomalies, usage data for each one-hour block during the course of the measurements. The remaining two sections provide mean usage within the receiver's spatial coverage for the two frequency bands.

A.1 Usage for Each One-hour Block During the Course of the Measurements

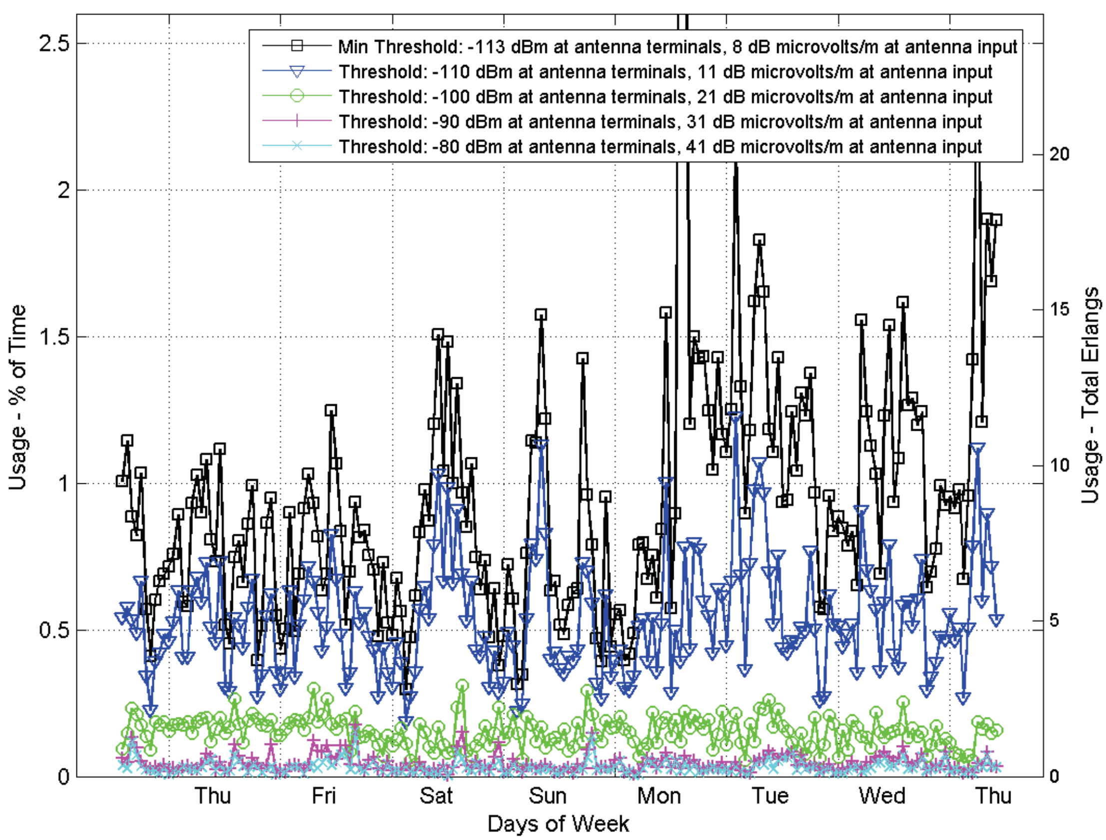

Figure A-1. *Hourly Band Usage* (percent of time and total Erlangs) during the course of the measurements for all 943 channels in the 162–174 MHz band.

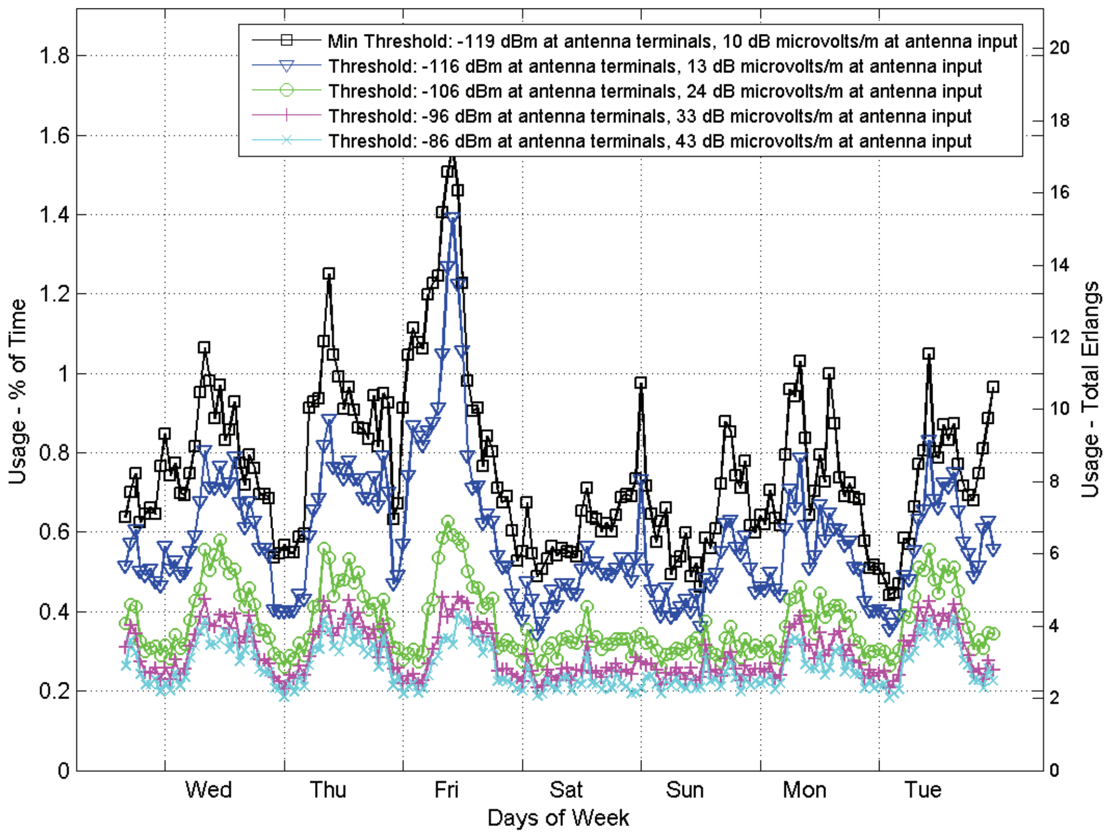

Figure A-2. *Hourly Band Usage* (percent of time and total Erlangs) during the course of the measurements for all 1,100 channels in the 406–420 MHz band (excluding HOCs).

A.2 Percent Band Usage for the 162–174 MHz Band

Tables A-1 through A-3 contain the *Percent Band Usage* data for the 162–174 MHz band for the *entire week*, *weekdays only,* and *weekends only*. For an explanation of how to interpret these tables, see Section 5.6 of [2]. The data is presented in terms of a 24-hour period and a period of 8 a.m. to 5 p.m. for each table. Note that for the *entire week* and *weekdays only* tables, data is included for the *Average of Busiest Usage by Hour*. That information is not relevant to the *weekend only* table and is not included for those measurement times since the busiest times happen during the weekdays.

Table A-1. *Percent Band Usage* and *Average of Busiest Usage by Hour* During the *Entire Week* for All 943 Channels in the 162–174 MHz Band

All Days	**Mean Detection Threshold**				
Threshold (dBm)	-113	-110	-100	-90	-80
Threshold (dBµV/m)	8	11	21	31	41
Timescale	**Percent Band Usage**				
% Band Usage (24 hours)	0.94 ± 0.01[14]	0.53	0.15	0.04	0.03
Average of Busiest Usage by Hour	2.04 ± 0.07[14]	Not Applicable			
% Band Usage (8 a.m. – 5 p.m.)	1.07 ± 0.02[14]	0.57	0.16	0.06	0.04
Note: 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 8.86 ((0.94 / 100) * 943).					

[14] 99 percent confidence level – assuming an **average** message length of no longer than 5 seconds.

Table A-2. *Percent Band Usage* and *Average of Busiest Usage by Hour* During *Weekdays Only* for All 943 Channels in the 162–174 MHz Band

All Days	**Mean Detection Threshold**				
Threshold (dBm)	-113	-110	-100	-90	-80
Threshold (dBµV/m)	8	11	21	31	41
Timescale	**Percent Band Usage**				
% Band Usage (24 hours)	0.99 ± 0.01 [15]	0.53	0.16	0.05	0.03
Average of Busiest Usage by Hour	2.25 ± 0.08 [15]	Not Applicable			
% Band Usage (8 a.m. – 5 p.m.)	1.12 ± 0.02 [15]	0.54	0.17	0.07	0.05
Note: 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 9.34 ((0.99 / 100) * 943).					

Table A-3. *Percent Band Usage* and *Average of Busiest Usage by Hour* During *Weekend Days Only* for All 943 Channels in the 162–174 MHz Band

All Days	**Mean Detection Threshold**				
Threshold (dBm)	-113	-110	-100	-90	-80
Threshold (dBµV/m)	8	11	21	31	41
Timescale	**Percent Band Usage**				
% Band Usage (24 hours)	0.78 ± 0.01[15]	0.52	0.14	0.04	0.03
% Band Usage (8 a.m. – 5 p.m.)	0.94 ± 0.01[15]	0.63	0.13	0.04	0.03
Note: 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 7.36 ((0.78 / 100) * 943).					

[15] 99 percent confidence level – assuming an **average** message length of no longer than 5 seconds.

A.3 Percent Band Usage for the 406–420 MHz Band

Tables A-4 through A-6 contain the *Percent Band Usage* data for the 406–420 MHz band for the *entire week*, *weekdays only,* and *weekends only*. For an explanation of how to interpret these tables, see Section 5.6 of [2]. The data is presented in terms of a 24-hour period and a period of 8 a.m. to 5 p.m. for each table. Note that for the *entire week* and *weekdays only* tables, data is included for the *Average of Busiest Usage by Hour*. That information is not relevant to the *weekend only* table and is not included for those measurement times since the busiest times happen during the weekdays.

Table A-4. *Percent Band Usage* and *Average of Busiest Usage by Hour* During the *Entire Week* for All 1,100 Channels in the 406–420 MHz Band (Excluding HOCs)

All Days	**Mean Detection Threshold**				
Threshold (dBm)	-119	-115	-106	-96	-86
Threshold (dBμV/m)	10	14	23	33	43
Timescale	**Percent Band Usage**				
% Band Usage (24 hours)	0.76 ± 0.01[16]	0.54	0.37	0.30	0.26
Average of Busiest Usage by Hour	1.35 ± 0.03[16]	Not Applicable			
% Band Usage (8 a.m. – 5 p.m.)	0.84 ± 0.01[16]	0.63	0.44	0.34	0.30
Note: 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 -119 dBm is 8.36 ((0.76 / 100) * 1100).					

[16] 99 percent confidence level – assuming an **average** message length of no longer than 5 seconds.

Table A-5. *Percent Band Usage* and *Average of Busiest Usage by Hour* During *Weekdays* for All 1,100 Channels in the 406–420 MHz Band (Excluding HOCs)

All Days	**Mean Detection Threshold**				
Threshold (dBm)	-119	-115	-106	-96	-86
Threshold (dBμV/m)	10	14	23	33	43
Timescale	**Percent Band Usage**				
% Band Usage (24 hours)	0.82 ± 0.01[17]	0.58	0.40	0.31	0.28
Average of Busiest Usage by Hour	1.53 ± 0.03[17]	Not Applicable			
% Band Usage (8 a.m. – 5 p.m.)	0.94 ± 0.01[17]	0.70	0.49	0.37	0.33
Note: 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 -119 dBm is 9.02 ((0.82 / 100) * 1100).					

Table A-6. *Percent Band Usage* and *Average of Busiest Usage by Hour* During *Weekend Days* for All 1,100 Channels in the 406–420 MHz Band (Excluding HOCs).

All Days	**Mean Detection Threshold**				
Threshold (dBm)	-119	-115	-106	-96	-86
Threshold (dBμV/m)	10	14	23	33	43
Timescale	**Percent Band Usage**				
% Band Usage (24 hours)	0.63 ± 0.01[17]	0.44	0.32	0.25	0.22
% Band Usage (8 a.m. – 5 p.m.)	0.58 ± 0.01[17]	0.44	0.32	0.25	0.23
Note: 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 -119 dBm is 6.93 ((0.63 / 100) * 1100).					

[17] 99 percent confidence level – assuming an **average** message length of no longer than 5 seconds.

APPENDIX B: WASHINGTON, DC AND DENVER, CO MEASUREMENT RESULTS COMPARISON TABLES

Tables B-1 and B-2 provide a summary and comparison of usage for the Washington, DC and Denver metropolitan area measurements in the two bands. Results in the 162–174 MHz band (Table B-1) show that the measurement data in these two areas indicate that Denver exhibits less usage. For example, the *Maximum Band Occupancy* for the 162–174 MHz band for all channels spaced 12.5 kHz apart was 1.6 percent for the DC area and 1.3 percent for the Denver metropolitan area. The percentage distributions for *Busiest Usage by Time-of-Day* also show a similar difference. The results show that the 162–174 MHz LMR band is being used to the expected degree in both metropolitan areas, with Washington, DC being the largest Federal LMR user area, and the Denver metropolitan area representing a medium-sized, dense Federal user area. The technology and data processing techniques used for the Washington, DC and Denver metropolitan area measurements can be used to perform future LMR measurements at other locations.

For the 406–420 MHz LMR band (Table B-2), the *Maximum Band Occupancy* was 2.7 percent for the Washington, DC metropolitan area, and about 0.95 percent for the Denver metropolitan area. Washington, DC shows a much higher usage in this band than the Denver metropolitan area. One observed reason is that Washington, DC is the headquarters for many Federal agencies and has much more activity than the Denver metropolitan area. Since the 162–174 MHz band was highly congested in the Washington, DC area, agencies tended to move to the 406–420 MHz band for their new LMR systems when the technology was available. Additional reasons for the difference may be researched in the future.

Table B-1. Usage Summary for Washington, DC and Denver Metropolitan Area Measurements in the 162–174 MHz LMR Band

Usage Items	Channel Spacing	Washington DC Area*	Denver, CO Area**
Total Number of Channels Analyzed [1]	12.5 kHz	934	943
Mean Detection Threshold		-113 dBm	-113 dBm
Band Occupancy by Time-of-Day	all 12.5 kHz	0.6–1.6 percent	0.6–1.5 percent
	old 25 kHz	0.9–2.2 percent	0.8–1.6 percent
	new 12.5 kHz	0.2–1.2 percent	0.4–1.2 percent
		(Figure 30)	(Figure 8)
Maximum Band Occupancy	12.5 kHz	1.6 percent for all channels	1.3 percent for all channels
		(Figure 30)	(Figure 8)
		2.1 percent for SLA only [2]	1.9 percent for SLA only [2]
Percent Band Usage (weekdays)	12.5 kHz	1.11 percent	0.99 percent
Percent Band Usage (8 a.m. – 5 p.m.)		1.53 percent	1.12 percent
Average of Busiest Usage by Hour		3.14 percent	2.25 percent
		(Table A-2)	(Table A-2)
Busiest Usage by Time-of-Day	12.5 kHz	60 percent channels exceed 1 percent usage	40 percent channels exceed 1 percent usage
		10 percent channels exceed 7 percent usage	10 percent channels exceed 5 percent usage
		1 percent channels exceed 34 percent usage	1 percent channels exceed 30 percent usage
		(Figure 34)	(Figure 12)

[1] NOAA Channels and HOCs (usage > 80 percent) are excluded.

[2] SLA: Specific Location Assignments

* Reference figures and tables in parentheses refer to [2].

** Reference figures and tables in parentheses refer to this report.

Table B-2. Usage Summary for Washington, DC and Denver Metropolitan Area Measurements in the 406–420 MHz LMR Band

Usage Items	Channel Spacing	Washington DC Area*	Denver, CO Area**
Total Number of Channels Analyzed [1]	12.5 kHz	1113	1100
Mean Detection Threshold		-117 dBm	-119 dBm [2]
Band Occupancy by Time-of-Day	all 12.5 kHz	1.3–2.7 percent	0.65–0.95 percent
	old 25 kHz	2.2–4.1 percent	0.95–1.45 percent
	new 12.5 kHz	0.4–1.5 percent	0.3–0.45 percent
		(Figure 42)	(Figure 20)
Maximum Band Occupancy	12.5 kHz	2.6 percent for all channels	0.95 percent for all channels
		(Figure 30)	(Figure 20)
Percent Band Usage (weekdays)	12.5 kHz	2.08 percent	0.82 percent
Percent Band Usage (8 a.m – 5 p.m.)		2.67 percent	0.94 percent
Average of Busiest Usage by Hour		4.29 percent	1.53 percent
		(Table A-6)	(Table A-5)
Busiest Usage by Time-of-Day	12.5 kHz	44 percent channels exceed 1 percent usage	12 percent channels exceed 1 percent usage
		10 percent channels exceed 13 percent usage	10 percent channels exceed 2 percent usage
		1 percent channels exceed 60 percent usage	1 percent channels exceed 40 percent usage
		(Figure 46)	(Figure 24)

[1] HOCs (usage > 80 percent) are excluded.

[2] For the Washington, DC measurements, the minimum threshold was -117 dBm. For the Denver measurements, the measurement system was improved to give an additional 2 dB of dynamic range.

* Reference figures and tables in parentheses refer to [2].

** Reference figures and tables in parentheses refer to this report.

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15. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

This report describes field measurements to characterize Land Mobile Radio (LMR) channel occupancy of Federal bands 162–174 megahertz (MHz) and 406–420 MHz at a single location overlooking the Denver, CO metropolitan area. This is part of the National Telecommunications and Information Administration effort to improve the spectrum efficiency of Federal radio usage. Measurements of the received radio traffic levels in these LMR frequency bands were performed over an eight-day period for the purpose of determining radio channel usage within the receiver spatial coverage of approximately 100 kilometer (km) radius for base stations, 50 km radius for mobile units, and 25 km radius for handheld units. The measurements were made using newly developed techniques that digitize as much as a 5 MHz segment of spectrum and process it to obtain simultaneous signal levels of up to 400 individual LMR channels. These techniques provided faster measurements, but also allowed enhanced post-processing of the data to remove effects of impulsive noise-like sources.

16. Key Words (Alphabetical order, separated by semicolons)

channel occupancy; channel usage; Federal radio usage; Land Mobile Radio (LMR); measurements; spectrum efficiency

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