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Measurements to Characterize Land Mobile Channel Occupancy for Federal Bands 162–174 MHz and 406–420 MHz in the Washington, D.C., Area

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ACRONYMS

ADC	analog-to-digital converter.
ACPR	adjacent channel power ratio.
APD	amplitude probability distribution.
CW	continuous wave.
dB	decibel.
dBc	dB relative to carrier power.
FFT	fast Fourier transform.
FM	frequency modulation.
HOC	high occupancy channel.
IM	intermodulation.
ITS	Institute for Telecommunication Sciences.
kHz	kilohertz.
LMR	Land Mobile Radio.
LO	local oscillator.
MHz	megahertz.
NOAA	National Oceanic and Atmospheric Administration.
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 4th generation measurement system.

DEFINITIONS

Adjacent Channel Power Ratio: The ratio in decibels (dB) between the total transmitter power that lies within its authorized channel bandwidth and the part of the output power that falls within the bandwidth centered around the frequency assignment of the adjacent channel (expressed in units of dBc).

Amplitude Probability Distribution: 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. A detailed description of APDs is given in a tutorial located in Appendix A of [1].

Area Assignments: Frequency assignments in the Government Master File that do not have specific coordinates and authorize base 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-5, and A-6.

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 29 through 31 and 41 through 43.

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 34 and 46.

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 27 and 39.

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 33 and 45.

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 five 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-five measurement technique. For example, if the five 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 35, 36, 47, and 48.

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% 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 26, 28, 38, 40, 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 32, 37, 44, and 49.

Maximum Band Occupancy: The maximum of all *Band Occupancy by Time-of-Day* values. This can be identified in Figures 30 and 42.

Occupancy: Channels are considered to be occupied (i.e., in use) whenever the channel contains Radio Frequency (RF) 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, weekend days, and Election Day. *Percent Band Usage* values are shown in Tables A-1 through A-8.

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 communication is 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 and automatically tuned to by 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, weekend days, and Election Day). 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 the Washington, D.C., area from October 26 to November 3, 2004 in the Land Mobile Radio (LMR) bands 162–174 and 406–420 MHz. The purpose of these measurements was twofold: first, to develop channel occupancy measurement techniques for LMR bands and secondly, to gather actual data on the usage of these bands in the Washington, D.C., area. The measurement techniques can be used at other metropolitan locations when the need arises to measure the LMR channel usage. The data gathered for this area and these bands will be used for further analyses of other aspects of the Presidential Spectrum Policy Initiative.

The measurements were conducted on the grounds of the partially abandoned Saint Elizabeth's Hospital, centrally located in the Washington, D.C., area, using the fourth generation of the Radio Spectrum Measurement Science (RSMS) system. The measurements were conducted 24 hours per day over the course of 8 consecutive days which included the Presidential Election Day. The measured data were post processed at the ITS Laboratory in Boulder, Colorado.

The measurement system was designed to have a coverage area of approximately 100-km radius for base stations, 50-km radius for mobile units, and 25-km radius for portable units. The measurement results are reported in terms of channel usage for designated LMR channels, irrespective of whether the individual channels have been assigned or not. The data, which was based on sampling the received power on individual LMR channels over an eight-day period of time and comparing those values to specific detection thresholds, was used to identify whether or not the LMR channels are being used at that location and to what extent.

Four types of data are presented in this report: 1) mean channel usage statistics, 2) mean busiest-hour usage 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/or 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 0.5 and 1.6 percent, with the busiest hours being between 7 am and 5 pm. For the 406–420 MHz band, the value was 1.2 to 3.6 percent with the busiest hours being between 5 am and 8 pm.

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). 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 1.6 percent is consistent with the recommendations made by the PSWAC.

Each of the two measured bands show approximately the same diurnal pattern of usage, irrespective of the measurement period (e.g., all days, weekdays, weekends, or Election Day), with slight variations between them. In the 162–174 MHz band, the highest usage occurs during the weekdays, exceeding the other time scenarios by about 1 percent. In the 406–420 MHz band, the usage was about the same for all of the time scenarios, except for about a 1 percent less usage on the weekend mornings, and about a 1 percent greater usage on the afternoon of the Presidential Election Day.

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).

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