Dynamic Spectrum Access Opportunities for Public Safety in Land Mobile Radio Bands

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***Abstract*—We present the results of a preliminary assessment of the potential for applying Dynamic Spectrum Access (DSA) methods to improve radio frequency spectrum utilization in the land mobile radio (LMR) bands in the U.S. This band includes both public safety and commercial user frequency assignments. First, using RF spectrum measurements made in Chicago, occupancy statistics in the widely used 450 - 470 MHz band are presented for several days during 2009 and 2011. The results show an increase in the average occupancy, and also in the total number of active channels detected. In view of the 2013 narrowbanding mandate from the FCC, a surprising find was that between 2009 to 2011, only about 10% of the wideband (25 kHz) LMR channels studied have shifted to 12.5 kHz transmissions. While the detected number of active LMR channels has increased by 15% in just 15 months, overall occupancy remains rather low, suggesting good opportunity for Dynamic Spectrum Access (DSA) systems, even with the impending transition to narrower channels. Finally, and somewhat opportunistically, we illustrate the effect of a major weather event (the Chicago Blizzard of 2011) on the utilization of the spectrum in the LMR band. The event reveals that while overall LMR utilization decreased during this weather event, public safety utilization increased, indicating that DSA could provide additional capacity for public safety during similar events.**

***Index Terms*—spectrum occupancy measurements; spectrum usage trends; dynamic spectrum access; public safety; land mobile radio**

I. Introduction

Nowhere is the need to make efficient use of the radio frequency spectrum greater than for systems deployed by public safety and first-responder agencies. While there is an unassailable need for access to spectrum by public safety organizations to accomplish their mission, spectrum allocated to public safety cannot usually generate revenue, either to governments via auction of spectrum rights, or to commercial entities via subscription fees. Since the RF spectrum has become a resource with a high economic value, it behooves regulatory agencies and system designers to make the most efficient use of spectrum allocated to public safety. It is for this reason that the study of methods to improve the effectiveness of RF spectrum utilization like Dynamic Spectrum Access (DSA) is attractive.

In the United States, Land Mobile Radio (LMR) channels have been allocated by the FCC primarily for voice communications by commercial as well as federal, state, and local government agencies [KOB01]. Today's conventional LMR technology consists of portable radios and/or repeaters with channel bandwidths of 12.5 and 25 kHz, utilizing either analog or digital modulation. In the future, 6.25 kHz bandwidth or equivalent may be required. Public safety agencies, like police and fire departments, use LMR systems for communication between dispatch centers and mobile agents in cars and on foot, or for direct mobile-to-mobile communications. Similarly, commercial users often employ LMR for "walkie-talkie" mode two-way communications, i.e. mobile-to-mobile. In 2004, the FCC issued a narrowbanding mandate [FCC04] requiring all LMR devices to switch from 25 kHz wide channels to more spectrally efficient 12.5 kHz ones by January 2013. The main reason for this is that in many urban areas, the limited number of channels available in the VHF (148 - 174 MHz) and UHF (450 - 512 MHz) LMR bands are for the most part, already allocated to specific users. By reducing channel bandwidths from 25 kHz to 12.5 kHz, the FCC will effectively double the number of available LMR channels, boosting the capacity for additional LMR applications. This transition has been enabled by the advances in wireless technology, which provide comparable voice quality while utilizing half (or even a quarter) of the original channel bandwidth.

Dynamic Spectrum Access technology allows radios to take advantage of RF channels that may have been assigned to specific users, but are underutilized [WYG09]. It provides the ability for users to efficiently use the same limited amount of spectrum by taking dynamic advantage of low occupancy channels. DSA technology, if applied to the LMR and public safety bands, has the potential to increase the number of possible users in a given spectral band far beyond that provided by narrowbanding. This paper examines both the current spectrum occupancy, and some of the trends in the utilization in the 450 - 470 MHz LMR band. With this information in hand, a cursory assessment of the feasibly of utilizing the DSA paradigms for LMR radio is provided. The basis for the spectrum occupancy observations and assessments is a set of RF measurements taken using the Spectrum Observatory at the Illinois Institute of Technology (IIT) in Chicago.

This paper is organized as follows: Section II provides an overview of the spectral measurements conducted; Section III presents occupancy statistics and trends including the impact of a significant weather event–the Chicago Blizzard of 2011–on the spectrum utilization; and Section IV examines DSA opportunities in the 450 - 470 MHz LMR band. Section V discusses some implications of this research for Public Safety

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users, and also demonstrates how public safety utilization changes during emergencies. Conclusions and future research opportunities are discussed in Section VI.

II. Measurement Overview

The IIT RF Spectrum Observatory was established in July 2007 to monitor radio frequency activity from 30 to 6000 MHz in the city of Chicago. The system is located in the 22 story IIT Tower (5.3 km south of downtown Chicago), whose roof provides an unobstructed view of Chicago's central business district for the antennas of the Spectrum Observatory. The major components of the Spectrum Observatory data acquisition system include: a spectrum analyzer (Rohde & Schwarz FSP-38), a pre-selector, three directional antennas and a desktop computer for measurements control and storage. More details can be found in [BAC08].

For the purposes of the study described in this paper, the wideband measurements from 30 - 6000 MHz were temporarily suspended in order to obtain high resolution time and frequency measurements of the LMR band between 450 - 470 MHz. A small 3 kHz resolution bandwidth was used and the average sweep time across the band was 10.9 seconds. This replicated another short term (5 day) study of the LMR bands conducted 15 months prior in October 2009 [BAC10].

In the previous paper [BAC10], results were presented of a long term (20 weeks) analysis of the average occupancy in the 450 - 465 MHz range: occupancy was found to vary between 35% and 55%. However, the shortcoming of that long term estimate was that the measurement data used for the particular analysis had a low frequency resolution (550 kHz). Consequently the occupancy from multiple (20+) LMR channels would be aggregated in each measurement point, inflating the results. For more accurate estimates of the occupancy in the LMR band, high frequency resolution data-sets are necessary where each LMR channel can be individually resolved. Hence, for this paper, the occupancy metrics in the 450 MHz LMR band were re-evaluated using such data.

III. Occupancy and Count of Active Users

Figure 1 shows the spectrum occupancy versus time plots for the 450 - 470 MHz UHF LMR band over a fifteen day period from January 26th to February 9th, 2011. The occupancy was calculated for three different sensing bandwidths: 3 kHz, the minimum resolution of the Observatory measurements; 12.5 kHz, the narrowbanding target channel bandwidth; and 25 kHz, the historic standard bandwidth for LMR. A 90 minute moving average filter was applied to smooth the results.

In Figure 1, the daily periodicity in the occupancy is readily seen over the two week period, as are the weekly cycles. The weekday activity is typically 35% higher than weekend activity, and has local minima around midday (during the lunch hour). Nighttime spectrum usage is also about 40% lower than the daytime value. The transient activity of LMR band occupancy was previously observed in [BAC10].

The 15 day span shown in Figure 1 includes measurements taken during the Chicago blizzard of 2011 [REU11] (with

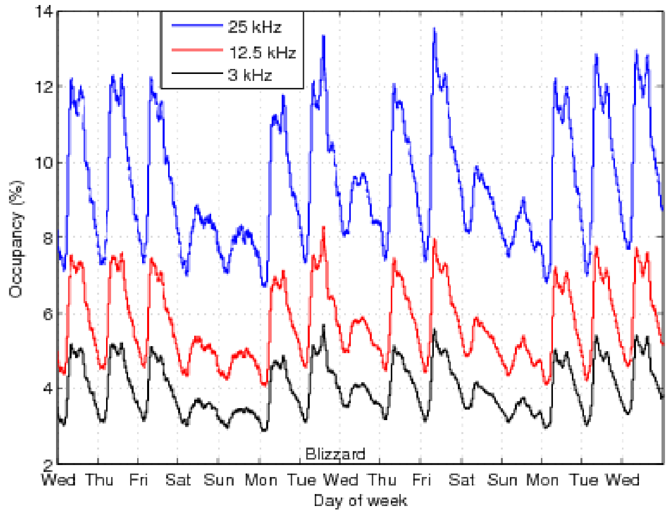

Figure 1. Occupancy vs. time for fifteen day period in 2011 for 3, 12.5 and 25 kHz bandwidths

roughly 0.5 m of snow falling in less than 24 hours between mid-afternoon of Tuesday, 1 February and approximately noon Wednesday, 2 February 2011). For reference, this was the highest snowfall in a decade, and the third highest snowfall recorded in Chicago after the blizzards of 1967 and 1999. The significant reduction in spectrum occupancy is readily visible in the plot, transforming the Wednesday utilization to roughly the level of a normal weekend. This observation seems very reasonable since all commercial activity virtually ceased on that day as the city was virtually paralyzed. Public safety utilization, however, increased, presumably due to an increase in the need for emergency responses (see Figure 5).

A comparison of the average occupancy levels calculated from high resolution measurement data in the 450 - 470 MHz UHF LMR band for October 2009 and February 2011 is shown in Table 1. These values were obtained by computing the percentage of the spectrum exceeding a threshold of -128 dBm/Hz (corresponding to a false alarm rate of 5% [HIP01]). The occupancy was calculated for the three bandwidths mentioned earlier and averaged over three day periods for each of the two years. As the occupancy is known to possess a weekly periodicity (see Figure 1), both years' data-sets were obtained over three typical weekdays (excluding storm days).

Table I
Spectrum Occupancies for 2009 and 2011

	Occupancy in bandwidth (b/w)		
Year	3 kHz b/w	12.5 kHz b/w	25 kHz b/w
2009	3.8 %	5.7 %	8.7 %
2011	4.8 %	6.7 %	10.9 %
Change	26 %	18 %	25 %

Though the absolute changes in Table 1 are relatively small, they represent a significant (~20%) increase in utilization over the 15 month period. Clearly the level of occupancy is affected by the sensing bandwidth; however an increase is apparent in all three bandwidths examined. A decrease may have been expected in view of the FCC's impending deadline for transitioning all wideband LMR channels to more spectrally efficient narrowband ones . To examine why the occupancy in fact increased, the data was analyzed further to estimate the total number of 12.5 kHz and 25 kHz LMR channels actively in use at our measurement location during October 2009, and how that changed in January 2011. The results are shown in the bar graph in Figure 2. An algorithm was used to classify 12.5 kHz and 25 kHz channels during 2009 and 2011, based on the distance between peaks in the average power spectrum and known channel center frequencies.

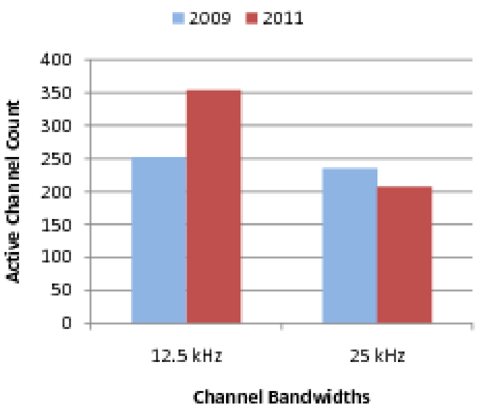

Figure 2. Number of 12.5 kHz and 25 kHz bandwidth transmissions detected for 2009 and 2011

The likely source of the increased occupancy in Table 1 appears to be a rather large 40% rise in the number of 12.5 kHz transmission channels detected in 2011 vs. 2009. This is expected and demonstrates that some LMR users are shifting to narrowband equipment, or that new users are purchasing 12.5 kHz equipment (a mandatory requirement for devices sold after January 1st, 2011). The number of 25 kHz transmissions shows only a slight decrease of 10% between October 2009 and January 2011, suggesting that other users may be slow to upgrade or are waiting until the last minute to do so. This observation is troubling, but not entirely surprising. A recent survey of LMR users revealed that only 25% of the respondents were both aware of, and currently meeting the narrowbanding mandate, and 31 % were either unaware, or did not have any plans to meet it [JAC11]. An examination of the public safety channels used by the Chicago Police Department (CPD) in the 460 MHz region showed only two 12.5 kHz channels operating in 2011, compared to none in 2009, while the twenty one 25 kHz channels are still being utilized.

The total number of LMR users detected, including both 12.5 kHz and 25 kHz channels, increased by 15% in 15 months indicating robust growth in LMR spectral demand. Narrowbanding should help by increasing the number of available LMR channels to satisfy this growth for several more years; but ultimately, if high LMR growth continues, then the new channels opened up by narrowbanding may soon (10 - 15 years) reach capacity. As such, fixed frequency allocation strategies including narrowbanding may be inadequate to meet the future requirements of public safety and commercial LMR users, and new approaches for increasing the number of available channels need to be investigated.

IV. Dynamic Spectrum Opportunities

The disparity between the high number of LMR users and low spectrum utilization discussed in the previous section, is largely a consequence of the traditional, but outdated, paradigm of fixed frequency allocations, whereby each user (or user group) is assigned their own physical channel, and relatively low spectral efficiency communication standards are employed. The 12.5 kHz and 25 kHz analog and digital standards used in LMR, for example, dedicate 64% and 60%, respectively, of the total channel bandwidth as guardbands [EMI11]. Furthermore, the voice transmissions on each channel typically have very low duty cycles [BAC10], meaning that most channels are unused for the majority of the time (as evidenced by the low occupancy numbers in Table 1). Many commercial LMR channels may only be used during the day and/or during weekdays, with lower average occupancy over weekends. Public safety channels typically have higher usage rates, and also show daily periodic trends with peaks during the day (or during emergencies) and lower usage at night [BAC10].

These observations indicate that there is considerable potential for dynamic spectrum access techniques to improve the overall spectrum use. This can be further quantified by examining a number of channel utilization metrics. The cumulative histogram of 12.5 kHz channel occupancies distributions is shown in Figure 3 for the 2009 and 2011 measurements. Note that the curve for 2011 is slightly lower than for 2009, which indicates an overall occupancy increase from 2009 to 2011. Nevertheless, both for 2009 and 2011, the plots show that a large percentage (about 60%) of the LMR channels are hardly used at all. More specifically, Figure 3 suggest that 80% of the channels have occupancy less than 10%; or in other words, 90% of the time 80% of all the LMR channels are unused. A future DSA enabled radio approach can take advantage of the spectral opportunity provided by the underutilized channels.

The spectral opportunity SO [MAR10] described in a frequency range can be defined as the complement of the spectrum occupancy OCC (i.e. $SO = 1 - OCC$) when the power measurements are performed with a sensor of bandwidth BW and a detection threshold, T. To calculate the SO, the power measurements are combined into bins of size BW. The fraction of the bins which are below the desired threshold T is then the opportunity. The spectral opportunity data can be normalized by dividing the total integrated power in each bin by the bin's bandwidth so that the threshold, T, now represents a fixed power density level. The spectral opportunity calculated in this way is a more practical expression of the prospect of improving spectrum utilization in a band, as it incorporates the bandwidth of the potential application as the parameter BW.

The spectral opportunity plots shown in Figure 4 show the amount of spectrum available in the 450 - 470 MHz LMR band over a 24 hour weekday for several receiver bandwidths,

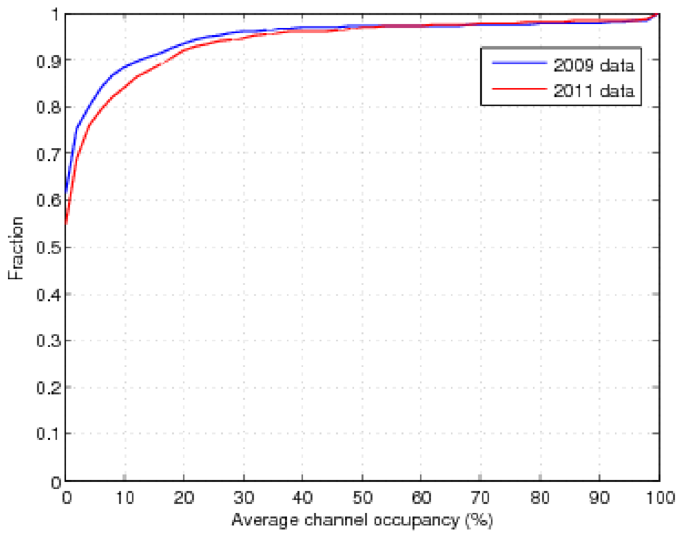

Figure 3. Cumulative histogram of 12.5 kHz bandwidth channels for 2009 and 2011 data

for the year 2011. In all three plots, it can be seen that there is a large amount of spectrum opportunity (assuming a threshold placed above the noise floor of approximately -130 dBm/Hz). Interestingly, the difference in opportunities for 6.25 kHz and 25 kHz sensing bandwidths is less than 10%, indicating that the potential benefit in switching to lower bandwidths is less significant for highly efficient DSA radios, at least in current spectrum conditions.

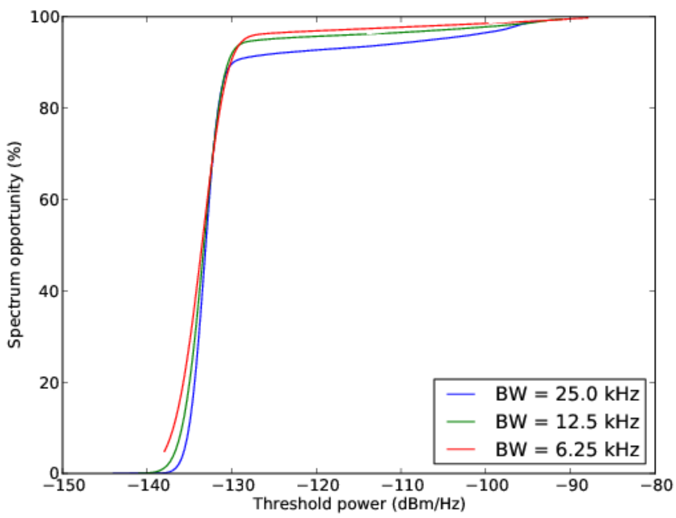

Figure 4. Spectrum opportunity for 2011 data with 6.25, 12.5 and 25 kHz bandwidths

V. Potential Implications for Public Safety

In aggregate, spectrum allocated for public safety voice and “narrowband data” communications in the U.S. totals about 39.7 MHz [TMO10]. This does not include some unused broadcast TV channels made available to public safety in some of the large metropolitan areas. Of this total, 3.7 MHz falls within the 450 - 470 MHz LMR band, and another 12 MHz falls in the 700 MHz region vacated in June, 2009, as a result of the digital TV transition and broadcast TV channel re-assignments. As described above, public safety voice systems within the 450 - 470 MHz band must transition from a 25 kHz voice channel RF bandwidth to a 12.5 kHz equivalent bandwidth by 2013. In the 700 MHz band, 6.25 kHz voice equivalent bandwidth has been mandated for all deployments.

Improving spectrum efficiency is of particular importance for public safety systems, not only in the 450 - 470 MHz band, but also in the 700 MHz band, where systems are just beginning to be deployed, and where there is necessity to optimize the overall use of the public safety spectrum to provide for both conventional voice systems as well as broadband data networks. The dynamic spectral opportunities discussed in Section IV are potentially useful for public safety policymakers who are exploring technologies and means to increase capacity for LMR voice communications such that the growing needs of the public safety community can be met years into the future.

The occupancy-versus-time plots in Figure 5 shows the average occupancy across the 21 Chicago Police Department (CPD) dispatch channels between January 26th and February 9th, 2011. For comparative purposes, the occupancy-vs-time plot from Figure 1 for the 25 kHz bandwidth has been reproduced in Figure 5 with a separate Y-axis. The 21 CPD channels are all 25 kHz in bandwidth and have center frequencies ranging from 460.000 to 460.500 MHz. The Governor of the State of Illinois issued a disaster declaration [ILL11] during the Chicago 2011 blizzard; during the emergency situation, the CPD radio usage was observed to be higher than typical, especially the nighttime activity. This is in contrast to the average occupancy across all LMR channels in the 450 - 470 MHz band, where the corresponding Wednesday (February 2nd) activity was much lower than normal.

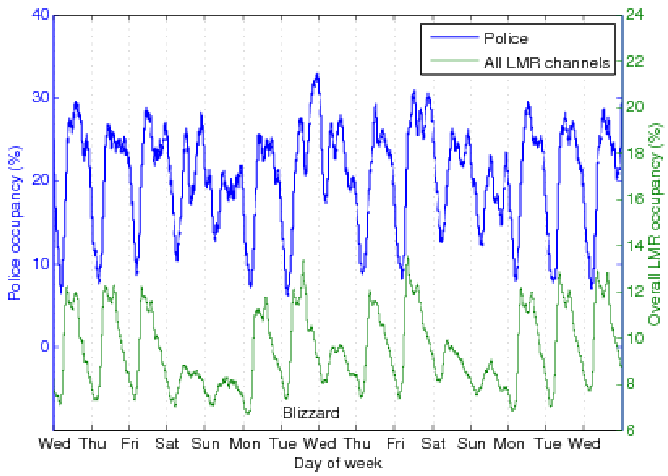

Figure 5. Occupancy vs. time of Chicago Police Department LMR channels for fifteen day period in 2011

The plots shown in Figure 5 have been smoothed with a 90 minute moving average filter, and the average occupancy for the CPD channels ranges between 7 to 32%. However, on multiple occasions, especially during the blizzard and for two days afterwards, the occupancy peaks between 90 and 100%. Due to the smoothing, some of this transient behavior is obscured and cannot be seen in Figure 5, but appears in the unfiltered data. This suggests that during emergencies, there are times where CPD radio usage approaches full capacity, and more channels may be needed.

During emergencies, it is likely that the demand for additional LMR channels by state and city public safety officials will go up, as suggested by the rise in CPD activity observed during the blizzard. At the same time, the overall occupancy in the LMR band (which largely depends on commercial and industrial users) could decrease, as it did on February 2nd, 2011. This represents an *increase* in the spectral opportunity for DSA enabled radios. The deployment of such radios in the future may actually provide first responders with additional communication capacity during natural disasters and other emergencies, exactly when it is most needed. While the one event observed above does not conclusively prove the value of DSA in the LMR bands, the measurement data strongly suggests that a significant increase in capacity for public safety users could be achieved if DSA were deployed, and that further investigation is warranted.

VI. Conclusions and Future Work

The results of the measurements performed in 2009 and 2011 provide additional insights into the dynamics of actual radio activity in the LMR bands. The low occupancies noted in both years were accompanied by an increase of 15% in the total number of channels actually being used. The growth rate indicates that the doubling of LMR channels resulting from the FCC's narrowbanding mandate, was (at best) timely, but still only represents a short reprieve from the increasing demands of the LMR community. Despite the imminent 2013 deadline for the narrowbanding mandate, an interesting result of the RF measurements taken was that apparently only 10% of 25 kHz radio users in 2009 have upgraded their equipment as of early 2011.

The occupancy variations across different LMR channels was investigated and it was found that most LMR channels are not in use the majority of the time. Our research shows that public safety users may have the most to gain from DSA applications in the voice LMR bands. The results also motivate a more comprehensive measurement and analysis program to determine specifically how DSA approaches might result in higher spectrum efficiency.

The studies reported here represent the initial results of a substantial effort that has been launched to more thoroughly and accurately assess the LMR communication bands, and in particular identify differences between commercial and public safety users. The results of this paper indicate that DSA techniques have the potential to significantly improve the efficiency of communication within the LMR bands, either allowing both more users, or even freeing up bandwidth for other uses in the future. For a true feasibility assessment, higher time and frequency resolution data is needed to determine the characteristics and requirements of public safety users, and whether DSA systems can be designed that can function in the dynamic environment resulting from many LMR users with varying activity levels. The high resolution measurements planned for future research will allow a total of 60 MHz of spectrum in three different LMR bands to be characterized with a high time resolution (~250 ms), permitting models of transient activity to be developed and studied for application to DSA radio simulation and design. Improved frequency resolution will also allow different LMR occupants (commercial, industrial, public safety) to be studied independently, so that their unique aspects and requirements can be better understood.

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