Time-dependent Statistical Analysis of Measurements for the Evaluation of Vacant Spectrum Bands

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Abstract

The demand for more bandwidth due to multi-media applications and the inherently finite resource ‘frequency’ require a more efficient use of the radio spectrum in future wireless systems. These requirements pave the way for the use of cognitive radios. This paper describes measurements that have been performed during the Soccer World Cup 2006 in Germany. Data is analyzed to obtain a suitable means to evaluate the vacancy of spectrum bands due to time-dependent statistics. This includes average channel allocation, average run length (sequence of ‘1’s in a binary allocation matrix), and amount of runs.

1. Introduction

The today’s spectrum regulation is characterized by a static allocation of frequency bands to services. These bands are reserved for exclusive use only by authorized subscribers. If these subscribers do not use their frequency bands, the available radio resources will remain unallocated. Resulting from several measurements, the overall spectral utilization is less than 20 percent within the frequency range between 30 MHz and 6 GHz [1,2]. In order to increase the utilization efficiency, new allocation mechanisms providing increased flexibility and frequency agility were proposed. These are dynamic spectrum access using overlay systems and cognitive radios (CRs) [3,4].

In order to increase the efficiency of spectral utilization, CRs can be used for overlay systems. In an overlay system the so-called rental users (RUs) are allowed to use radio channels that are not allocated by the users of the established licensed system. All subscribers of an established licensed system like, e.g., GSM, UMTS, or WiFi, are named licensed users (LUs). In order to avoid illegal interferences between both systems, an adequate LU detection has to be provided by the rental system. Furthermore, a CR system needs to support a wide frequency range for supporting an increased flexibility in spectrum access. Flexibility in this sense means, the CR system is able to move the current radio communication from one subband to another in case of an increasing radio traffic load in the LU system. In this wide-band CR system the utilization of the supported subbands has to be considered in order to choose the most suitable one. The paper is organized as follows. Section 2 describes the measurements that have been performed during the Soccer World Cup 2006 in Germany. In Section 3 the results of the measurements are presented with respect to time-dependent statistics. The outcomes of the results and their feasibility for the evaluation of vacant frequency bands are discussed in Section 4. Finally, Section 5 concludes the paper.

2. Measurements

2.1 Configuration

Four different measurement configurations have been used [5,6]. (1) GSM 900 downlink band with a frequency resolution of 200 kHz and one spectrum snapshot every second. (2) GSM 1800 downlink band with a frequency resolution of 200 kHz and one spectrum snapshot per second. (3) UMTS downlink and WiFi with a frequency resolution of 1 MHz and one spectrum snapshot per second. (4) Global band from 400 MHz to 2600 MHz with a frequency resolution of 2 MHz and a spectrum snapshot every 4 seconds.

2.2 Procedure

The measurements were performed with an omni-directional antenna placed at 4 m height above ground (mounted on a van) that has been connected to a spectrum analyzer. To be able to measure the aforementioned radio technologies simultaneously, four measurement set-ups have been run in parallel. The spectrum analyzer was controlled by the EM Spy Software developed by France Telecom. Memory size of the analyzer and consequent tradeoffs between time and frequency resolution allowed automatic recording periods of about 30 to 45 minutes without any manual intervention. Several cycles were therefore programmed to cover the whole duration of a soccer match and some time before and after the match as well to obtain knowledge about the user behavior after such a mega-event [5,6].

The measurements were collected at two distinct but fixed locations. First, measurements in Kaiserslautern where the match Italy versus USA took place were collected, and second, in Dortmund where the match Germany versus Poland was hold. An important issue with respect to the importance of such an event was to find adequate locations that were likely to give relevant information on wireless activity. In addition to that, it was important to keep the same location for the measurements the day before the match and the day of the match to have similar environmental circumstances for comparison of the collected measurement data.

In Kaiserslautern the vans were located in a parking lot approximately 400 meters away from the stadium entrance and not more than 30 meters from a direct footpath to the stadium. There was a significant amount of vegetation, mostly trees, and since the measurements were performed in summer, maximum blockage by the foliage could be expected. This issue is of great importance for the single measurement sets, but can be neglected if different sets are compared with each other as they have been influenced in the same way. In Dortmund the vans were located between the city center and the stadium on one of the paths to the stadium marked by the Organization Committee. Therefore, this location provided a good opportunity to exploit “moving spots” due to pedestrians. There has been less vegetation compared to Kaiserslautern, but more houses and apartment buildings. Collected data have been stored in a frequency-time matrix. Data have been post-processed to derive a binary allocation matrix. This means, each matrix input above a threshold value of -90 dBm was set to ‘1’ (allocated) and each matrix input below this threshold was set to ‘0’ (not allocated). The threshold has been selected with respect to measurement settings, e.g., resolution bandwidth and noise figure of the spectrum analyzer.

3. Results

As already mentioned in the introduction, this study is concerned with time-dependent statistical analysis of the measurement data. A well-known and often used method to show time-dependencies of channel allocation is the complementary cumulative distribution function (CCDF). It describes the probability that a signal is above a specific power value and, hence, CCDF is a suitable means to characterize the peak power statistics of digitally modulated signals. Consequently, if we consider a CCDF curve, we will only know that a channel has been occupied for, e.g., 70 percent of the measurement time. However, we gain no knowledge about the actual time when this channel has been allocated and could not be used for secondary usage. To overcome this drawback, we made further analysis. First, we calculated the average channel allocation (%) which is identical to the mean that can easily be calculated from the CCDF. Second, we calculated the average run length (min). A run describes a sequence of ‘1’s in the binary allocation matrix. Third, the amount of runs within the measurement time has been calculated, thus providing information about the frequency of the channel access.

We omit the presentation of all measurement results and focus on the GSM 1800 system. Fig. 1 shows the results for the measurements collected in Dortmund during 7.30 p.m. and 8 p.m. the day before the match. We can already see that a high occupancy can be recognized even the day before the actual event took place (see ‘Average channel allocation [%]’). However, this is mostly due to the chosen measurement set-up as described before. Furthermore, the average run length as well as the amount of runs is strongly varying. Fig. 2 illustrates the spectrum allocation on the day of the match between 7.17 p.m. and 7.47 p.m. The situation is slightly different. For instance, all frequency bands between 1825 MHz and 1847 MHz are practically occupied all the time. This is in line with the average run length that now shows much less variation compared to Fig. 1. Consider the frequency 1832 MHz. The average run length is approximately 10 min and the amount of runs is 3. Hence, there are only two small spectrum opportunities which are not usable for secondary usage due to their shortness in time. Further discussion of the results is given in Section 4.

4. Discussion

As indicated above, our analysis gives a better understanding of the spectrum usage situation than a CCDF alone gives. We do not only gain knowledge about how many percent of the measurement time a signal has been above a predefined threshold – which indicates an allocated channel – but also about the amount of channel access (‘Amount of runs’) and their average duration (‘Averaged run length [min]’).

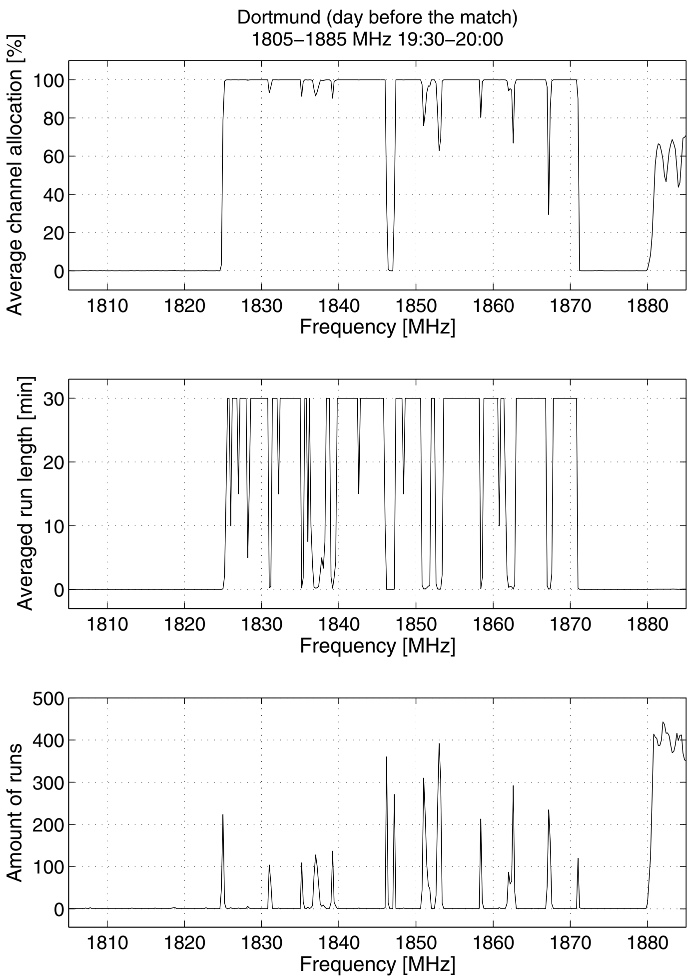

Fig. 1: Average channel allocation [%], average run length [min], and amount of runs for measurements performed in Dortmund between 1805 MHz and 1885 MHz the day before the match Germany versus Poland.

Indeed, this analysis is a great step forward, but not yet sufficient. As an example consider the frequency 1867 MHz in Fig. 1. Average channel allocation is 30 percent, and thus this frequency can be used for 70 percent of the measurement time for secondary usage. However, the amount of runs equals 230 with an average run length of 0.04 min. If we assume uniform distribution of the runs over time, we will have 230 spectrum opportunities, each of length 0.09 min which is not useful for secondary usage. The best case, however, is that we have 229 spectrum opportunities of minimal length (consisting of only one ‘0’) and one spectrum opportunity of maximal length. This would then result in a spectrum opportunity of approximately 17.2 min which would definitely be applicable for secondary spectrum usage. This drawback can be overcome if the standard deviations of the run lengths are calculated, too.

5. Conclusion

This paper is concerned with spectrum measurements performed during the Soccer World Cup 2006 in Germany. The analysis and data processing has been done with respect to time-dependent statistics to be able to gain deeper knowledge about the actual spectrum situation. The analysis started with average channel allocation that simply represents the mean of channel occupation and could also be calculated by use of the complementary cumulative distribution function. Additionally, the average run length and the amount of runs on a specific frequency band have been calculated. A run represents a sequence of ‘1’s in the binary allocation matrix. Combination of these three analysis outcomes gives a clearer understanding of spectrum occupation which is of enormous interest for the provision of secondary spectrum usage with cognitive radios. Nevertheless, further research on this topic is necessary. For instance, standard deviation of run length is indispensable to increase the degree of reliability in the classification of vacant frequency bands.

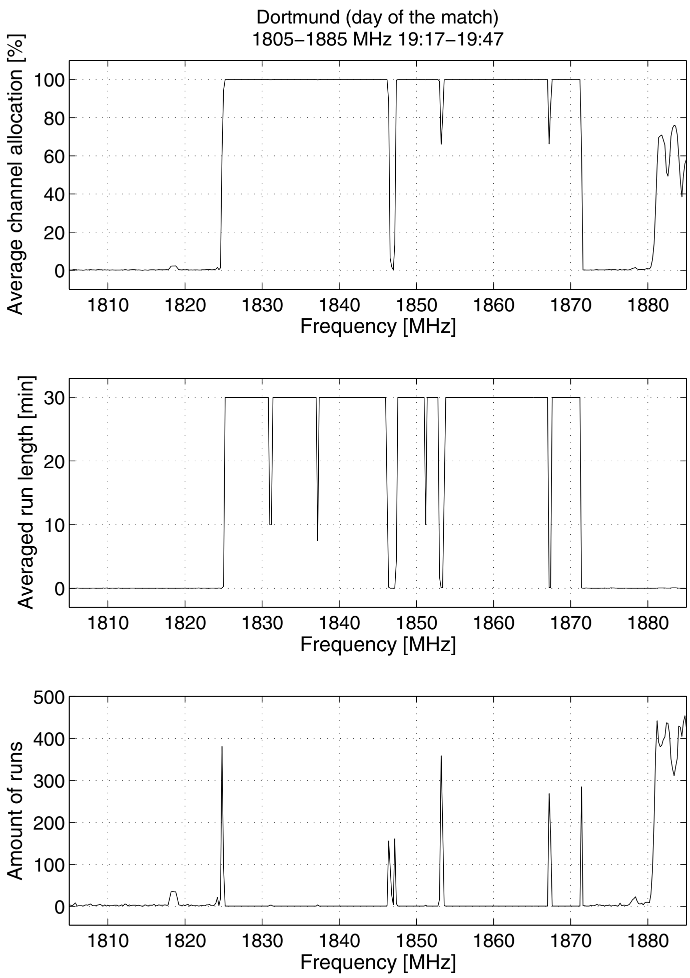

Fig. 2: Average channel allocation [%], average run length [min], and amount of runs for measurements performed in Dortmund between 1805 MHz and 1885 MHz the day of the match Germany versus Poland.

6. References

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