Coexistence analysis and cognitive opportunities selection in GSM bands

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Abstract— This paper presents a characterization of spectrum opportunities in GSM900 downlink bands, for fixed and mobile scenarios. A testbed to analyze coexistence between the licensed GSM900 downlink system and an OFDM based secondary system that opportunistically shares the same spectrum is presented. Coexistence analysis is based on metrics such as spectrum collisions rate and the secondary system throughput. Using this testbed a cognitive mechanism to classify and select stable opportunities is evaluated in realistic scenarios.

Keywords—Cognitive radio, GSM900, coexistence, sensing.

I. INTRODUCTION

It is expected that the demand for wireless services will continue to increase in the near and medium term, calling for more capacity and putting more and more pressure on the spectrum availability. While the use of advanced signal processing techniques may enable a very efficient usage of the spectrum even in the traditional framework of command and control spectrum policy, there is a worldwide recognition that these methods of spectrum management have reached their limit and are no longer optimal and new paradigms must be sought [1]. In fact independent studies carried out in different places (e.g. [2]) have shown that most of the assigned spectrum is under-utilized. Thus the problem is in most cases a problem of inefficient spectrum management rather than spectrum shortage. The development of frequency agile terminals that can sense “holes” in the spectrum and adapt their transmission characteristics to use these “holes” may provide one tool to address and take advantage of this spectrum under-utilization. The evidence of the change and evolution in the approaches of spectrum management can already be seen in the development of the IEEE 802.22 cognitive radio based standard for fixed, point-to-multipoint, wireless regional area networks that operates on unused channels in the TV VHF/UHF bands between 54 and 862 MHz on a secondary basis [3].

Currently there are few studies addressing coexistence between licensed and secondary systems sharing the same spectrum in an opportunistic way. The great majority of the current available studies addressing coexistence between wireless standards are focused in ISM bands, e.g., [4] present empirical study addressing coexistence between IEEE 802.11g and 802.15.4 in the 2.4 GHz ISM band.

In this paper we carry out coexistence analysis between the licensed GSM900 standard (primary system) and a secondary system, based on OFDM transmission. A coexistence testbed is presented to evaluate the spectrum collisions rate and the secondary system throughput. In line with the cognitive radio definition [5] i.e., a system able to exploit past information, learn the primary user behavior and adjust according to some objectives, a cognitive mechanism to select stable opportunities is integrated and evaluated in realistic scenarios.

This paper is organized as follows: In Section II a characterization of opportunities in GSM900 downlink bands is performed. In Section III a testbed for coexistence analysis is presented. In Section IV a cognitive mechanism for opportunities selection is tested and some illustrative results are presented, finally, in Section V conclusions are made and future challenges highlighted.

II. OPPORTUNITIES IN GSM900 DOWNLINK BANDS

GSM900 uplink band is from 890 to 914 MHz and the downlink band is from 935 to 959 MHz. Each band contains 124 carrier frequencies separated by 200 KHz. Figure 1 contains plots of the spectrum occupancy measurements for GSM900 downlink bands. The measurements were collected in a fixed location in a university building’s roof over four consecutive days, starting at 00:00 AM. The measurement site is surrounded by a dense urban scenario in Castelo Branco city in Portugal.

The occupancy level of GSM900 downlink band, defined as the average duty cycle based on the time-frequency product is 67.8%, which means that even in dense urban areas there are opportunities in GSM900 bands. From Figure 1 we can see that many GSM data channels present a pretty periodic pattern of occupancy, alternating between high occupancy during the day and idle periods during the night hours, i.e., with the detected signal under the defined threshold (-100 dBm). To emphasis this, Figure 2 shows the average Power Spectrum Density (PSD) measured in a particular GSM900 downlink data channel at 939.2 MHz; a periodic patter with a minimum at 6 AM and 24 hours period is very clear. In the same plot it is shown a GSM900 downlink control channel, centered at 942 MHz, where the received power is almost constant during all the period analyzed. Sensing this control channel could be a way to compute the path loss between the GSM base station and a secondary terminal. This path loss can be used by the secondary system to compute the maximum
allowed transmitted power, avoiding harmful interference with the GSM base station, as proposed in [6].

Figure 1 Measurements in GSM 900 downlink band. Urban scenario with fixed site.

Previous spectrum occupancy measurements were obtained with the sensing antenna at a fixed location, however, in real applications it is expected to have mobility on secondary terminals. Mobility changes the propagation channel between the primary user and the secondary terminal’s antenna. In fact, if a secondary terminal is moving, the primary user’s signal could be shadowed by obstacles, causing temporal signal drops which duration depends on secondary terminal speed and the propagation environment. Interestingly, although it seems to be an important point for dynamic spectrum research, we have not seen any analysis in the literature considering mobility in secondary terminals. To address this topic, a measurement campaign was carried out for GSM900 downlink band with the measurement setup inside a vehicle moving at 40 km/h for different propagation scenarios: urban, suburban and rural. Measurements were performed during 30 minutes in the rush hour of a weekday. Data were collected through a Labview™ application for further analysis. Figure 3 shows the spectrum occupancy results. Comparing Figure 3 with Figure 1 (fixed location), we can see that mobility completely changes the spectrum occupancy pattern, becoming more random and irregular. Therefore, any predictive models used to forecast opportunities based on primary user past behavior, e.g. [7] should be carefully reconsidered when mobility of secondary users is take into account.

Based on data from Figure 3, the duration of opportunity (time that the GSM channel is continuously unused, i.e., below threshold level) is computed for each of the 124 GSM channels. Figure 4 and Figure 5 show the histogram of opportunity’s duration in GSM downlink band for urban and rural scenarios, respectively. From Figure 4 opportunities observed in urban scenarios can be approximated by an exponential distribution. However opportunities in rural scenario tends to follow a more uniform distribution, for instance the probability to observe an empty channel (1800 seconds) is similar than the probability of opportunities with 180 seconds duration.

Figure 3 Measurement obtained with the secondary user moving at 40 km/h in urban scenario.

Figure 4 Histogram of duration’s opportunities in urban scenario.
III. TESTBED FOR COEXISTENCE ANALYSIS

Spectrum measurements in GSM900 downlink band showed a very dynamic RF behavior, special when mobility is considered. While sensing algorithms is not the focus of this paper, its performance has heavy impact on coexistence. Due hardware limitations, it is usually assumed that the opportunistic terminal cannot sense and transmit simultaneously, thus a “listen before talk” approach is considered. Secondary data signal is transmitted after the sensing process and throughout a communication time slot following the frame structure showed in Figure 6. Sensing is a periodic process. The optimal sensing period, T, depends on the tradeoff between a reliable sensing, i.e. a short period, and low sensing overhead, i.e. a long period. In dynamic RF environments, such as GSM bands, an excessive value of T can easily leads to collisions with the primary system. Figure 6 also illustrates the temporal evolution of a particular subcarrier’s power. At the sensing time the detected power is below to the TH level, so an opportunity was detected, however, due changes in RF environment and propagation conditions, interference with the primary system will occur during the secondary data transmission (marked as X). These spectrum collisions can be reduced trough a care selection of the sensing period, and applying opportunities filtering mechanisms, this topic will be further discussed in section IV.

Figure 7 Testbed for coexistence analysis.

Figure 8 illustrates a snapshot of the GSM900 downlink spectrum in an urban scenario. This spectrum was measured 5 seconds after the sensing time. The related secondary OFDM spectrum is also showed with 125 activated subcarriers and 387 subcarriers switched off. Among them, 3 subcarriers were reported as collisions events by the coexistence analysis module (marked as X). Moreover, the average secondary throughput reported is 3.6 Mbit/s.

To evaluate coexistence, exhaustive tests were carried out with the coexistence testbed, results are presented in Figure 9 for different scenarios: urban, suburban and rural. Figure 9 shows the average secondary throughput as a function of the average collisions rate, i.e., the percentage of the 512 subcarriers where collisions were reported. The associated sensing period, T, is also showed. As expected, the higher is the sensing period, the higher is the average collision rate. We also observe a tradeoff between the percentage of collisions and the secondary throughput. The secondary throughput grows almost exponential at small percentage of collisions (0-4%) but slowly converge to an asymptotic value as the percentage of collisions increases. Obviously, the highest
throughput is achieved in rural scenarios, since there are less GSM channels occupied. These results pointed out that a sensing period equal to $T=10$ s, leads to an average collision equal to 15% for rural scenario and 21% for suburban and urban scenario. The next step is to develop opportunities selection mechanisms to decrease the collision rate.

Figure 8 Sample of the testbed graphical interface, urban scenario, 40 km/h.

Figure 9 Coexistence analysis between the secondary system and the GSM for different RF scenarios, speed=40 km/h.

IV. COGNITIVE OPPORTUNITIES SELECTION

The dynamic nature of secondary systems makes channel access relatively unstable compared to conventional systems. Thus, the goal of spectrum sensing is to provide the best quality frequency bands for opportunistic usage to maximize persistence of allocations while avoid interference with primary users. Persistence is essential to the stability of the overall secondary system. It reduces overhead cost of spectrum allocation system by reducing the risk for future spectrum thrashing and the need for additional spectrum negotiations and reconfiguration delays. To avoid unreliable opportunities with frequent interruptions of GSM signals we integrated a “Quality of Opportunity” module in the coexistence testbed, as showed in Figure 9. This new module, takes input from past sub carriers allocations, computes the quality of the opportunity, based on a quality metric, and applies a threshold based filter to eliminate unstable opportunities. The filter threshold ($THQ$) is reconfigurable, and offers the capability to control the trade-off between aggressive spectrum access towards maximizing spectrum utilization, and conservative spectrum access for minimizing collisions with GSM and maximizing stability of secondary spectrum allocation. To measure the quality of opportunity we apply the availability metric proposed in [9],

$$Q = \mathbb{E}\left\{\frac{\Delta}{W \cdot N_i}\right\}; \quad 0 \leq Q \leq 1 \tag{1}$$

Where, $i=1,...,512$; $W$ is the observation window considered; $\Delta$ is the total opportunity duration over interval $W$ and $N_i$ is the number of GSM signals switches to frequency $i$. This metric captures both the average duration of each spectrum opportunity and the frequency of interruptions from GSM signals (related to the opportunity’s stability). A secondary system can use this metric to schedule their spectrum usage, such as selecting the frequencies with the highest $Q$. Figure 10 shows the availability metric computed in urban scenario using a window $W=100$ s and $T=10$ s. A quality filtering is included in order to eliminate opportunities with $Q<0.6$.

Figure 10 Testbed for coexistence analysis with cognitive opportunities selection.

Figure 11 Availability metric, $Q$, computed in GSM downlink band for urban scenario.
Figure 11 and Figure 12 show the outputs of the coexistence testbed, i.e., the averaged throughput of the secondary system and the average number of spectrum collisions, respectively, as a function of the opportunities selection threshold level THQ. The use of a high value of THQ can effectively decrease the spectrum collisions and increase opportunities’ stability; however this is achieved at the cost of secondary throughput decrease. Nevertheless we can envisage mechanisms as high order modulations and bit loading over the high quality selected subcarriers to provide higher bit rates.

V. CONCLUSIONS AND FUTURE WORK
This paper illustrates the feasibility of secondary spectrum access in dynamic RF environments, in particular, over licensed GSM downlink band. A cognitive mechanism that uses past information to select stable opportunities was integrated and evaluated using a coexistence testbed. Coexistence analysis based on spectrum measurements showed that in an urban scenario, with mobile speed equal to 40 km/h, a sensing period equal to 10 s leads to collisions average equal to 2% and a secondary bit rate equal to 1.8 Mbit/s. As future work we will investigate opportunities scheduling algorithms to guarantee QoS for demanding secondary user applications.

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REFERENCES
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