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MARKOV MODEL FOR HF JOINT SPECTRUM OCCUPANCY AT TWO DISTANT LOCATIONS

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Abstract: *Even with the present-day development of mobile communications in UHF and SHF spectral bands and recent trends to move to mmWave, HF radio communications still offer advantages that make them exclusive in some application areas. Cognitive Radio principles can be applied to HF communications, to make use of the spectrum more efficiently. A significant improvement of Cognitive Radio technique can be achieved by spectrum occupancy prediction, which enables proactive efficient spectrum utilization. Hidden Markov Models (HMM) can be a useful tool for statistical spectrum occupancy prediction. In some of our previous works, we investigated a simple HMM in time domain, as well as a bidimensional model, that take into account both the time domain and the frequency domain. In this paper, we propose to extend the coverage of the model, by considering in addition to time and frequency the geographical position of the two points involved in the radio connection. The work is motivated by the fact that the two points of the radio link in HF can be far apart, and the channel availability at the two points could be different. Therefore, finding and exploiting correlations between the spectrum occupancy at the two points might improve the connectivity. The proposed model is validated using real spectrum occupancy data collected simultaneously at two locations situated in two cities, namely Timișoara and Sibiu, Romania. The measurements have been made using two identical USRP equipment, GPS coordinated, and identical HF broadband antennas.*

Keywords: High Frequency, Joint Spectrum Occupancy, Markov models, Cognitive Radio

1. Introduction

In the modern Cognitive Radio paradigm, users divide communication in two separate activities: spectrum sensing and data transmission. As a result, throughput is increased, and energy consumption reduction is achieved [1].

Present-day trends are directed towards building communication systems in the GHz and mm-wave range due to high spectrum availability and opportunity for achieving large relative transmission bandwidth. However, line-of-sight propagation that is associated to Ultra- and Super-High-Frequency domains is not appropriate for some specific terrain morphologies and for applications involving e.g. emergency situations and deployment of military troops. Therefore, High-Frequency (HF) based communication systems are still subject of intensive research [2,3].

Applying Cognitive Radio concepts to HF communication systems needs empirical

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knowledge of noise floor in the 3-30 MHz range [4] and construction of models for the spectrum occupancy (SO) or availability. SO measurement procedures have been proposed, refined and discussed in the literature [5]. Extensive measurement campaigns have been carried over in various parts of the world; see e.g. [2, 3, 6].

Planning of Cognitive Radio activities needs models for the spectrum availability in order to apply the concept of opportunistic access. Several types of models can be fit to SO data, such as time series models, neural networks, cumulative distribution function, probability density function, linear regression models, Markov chains, spectrum prediction by ARMA and MA models etc. [1]. For example, time series models have been proposed for the HF spectrum occupancy in the Eastern Mediterranean region [2], neural networks models have been constructed for the Northern Europe [3], Markov models have been applied to spectrum occupancy in Central Australia [6] , Hidden Markov models have been discussed in [7] etc.

The authors of this paper have been interested in the past in application of Markov models to spectrum occupancy data measured at the location of Timişoara, Romania [8]. However, since a communication link involves (at least) two participants, meaningful planning of the link requires modeling the joint spectrum occupancy at the locations involved.

Joint spectrum occupancy data have been measured by means of GPS synchronized NI-USRP software defined radio equipment at the locations of Timişoara and Sibiu, Romania and results have been reported in [9]. Time (corresponding to one frequency channel), frequency (corresponding to adjacent channels) and time-frequency models have been considered. Spectrum occupancy has been measured according to an energy detection threshold procedure [1,9].

In this paper, we report the results of applying Markov models to the joint spectrum occupancy for the two locations. In Section II, the procedure to measure SO is described, and Section 3 introduces two conditional probabilities to characterize the joint SO in time and in frequency domain. Conclusions and future work are the subject of the last section. This work aims at applying cognitive radio solutions in the future to the Automotive industry.

2. Spectrum occupancy measurement

Spectrum occupancy measurement have been performed in two locations in Romania, namely Timişoara and Sibiu. In the two locations, identical equipment has been used, comprised of SDR NI USRP-2950 Dual RF Transceiver and broadband antenna model DiamondWD 330 J. To operate the SDR equipment in the HF range, an extension LFRX USRP Daughterboard had to be added, providing the operational frequency range DC-30 MHz. The communication with host computer has been achieved through a PCIe–MXI Express Interface Kit for USRP RIO. The system has been controlled and operated under the GNU radio environment. To provide accurate time synchronization both USRPshave been equipped with GPS-disciplined oscillator (GPSDO) and GPS external antenna. A Python script was used for synchronous signal recording at the two locations, at various central frequencies and bandwidth. Records have been repeated with a given period for a certain time duration, and split off-line in small sub-records in time domain.Figure 1 plots the sub-record spectra for the two locations. Every record has been split into sub-band (channels) of bandwidth B, according to the intended communication mode, and the spectrum occupancy has been computed on each sub-band using energy detection criterion according to

$$T(f) = W(f) + W_M \tag{1}$$

where $W(f)$ is the noise floor and W_M is a fixed margin. The noise floor for energy threshold was computed by splitting the

signal bandwidth in narrow sub-bands and considering that the sub-band having the smallest energy contains only noise.
Figure 2 illustrates the method for finding the noise floor (in red) and the threshold (black line).

Simultaneous spectrum occupancy for 24 hours (starting at 9 a.m.) in the two locations, shown in Figure 3 displays very high similarities leading to the idea of joint spectrum occupancy.

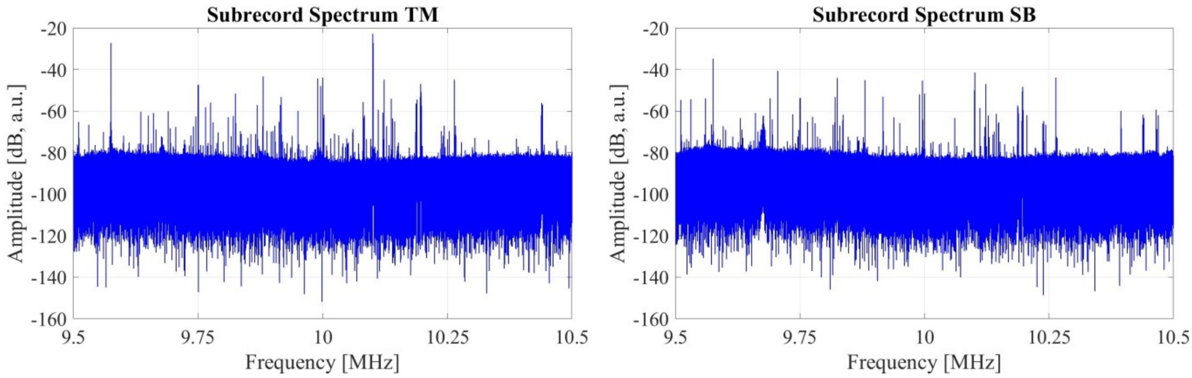

Figure 1: Simultaneous spectrum for the two locations

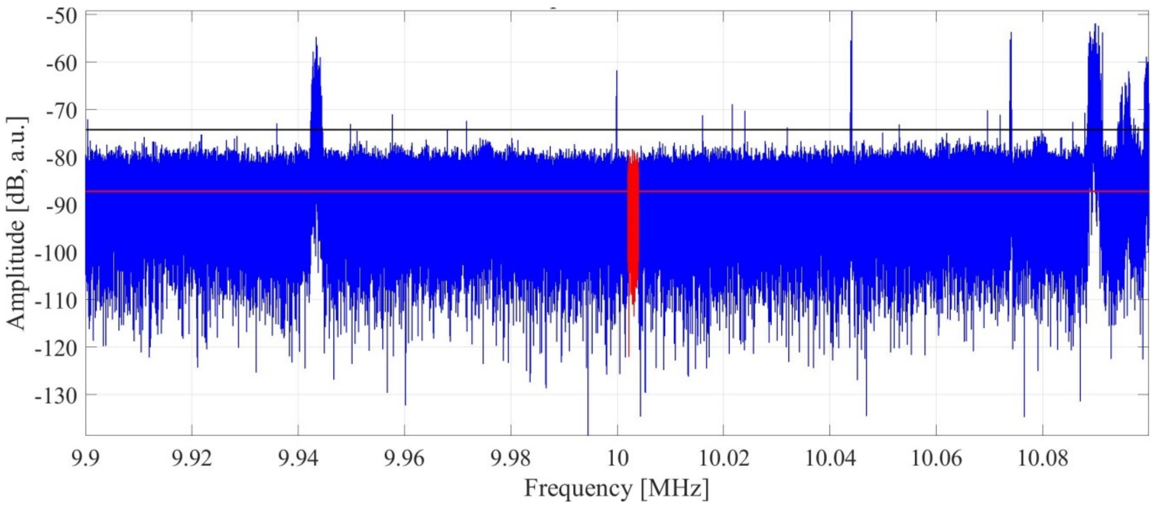

Figure 2: Noise floor and threshold finding method

3. Joint Spectrum Occupancy

The spectrum occupancy state, either free or occupied, was considered as an instantaneous state. In the following we consider first that the current spectrum occupancy state depends on the previous state, i.e., the spectrum occupancy states follow a Markov chain of first order. Using the notation:

$$p = \mathrm{P}[x_n = 1], \quad \lambda = \mathrm{P}[x_n = 1 \mid x_{n-1} = 1] \quad (2)$$

where x_n denotes the SO at instance n, we have

$$\begin{aligned} &P[x_n = 0] = 1 - p = q, \\ &P[x_n = 0 \mid x_{n-1} = 1] = 1 - \lambda \end{aligned} \quad (3)$$

where p and q are the probabilities to detect the states 1 and 0.

Using the notation

$$\Phi_{i,j} = \mathrm{P}[x_n = i \mid x_{n-1} = j], \quad i,j = \{0,1\} \quad (4)$$

the steady states for the first order Markov process are the solution of:

$$\begin{aligned} q &= q\Phi_{0,0} + p\Phi_{0,1} \\ p &= q\Phi_{1,0} + p\Phi_{1,1} \end{aligned} \qquad (5)$$

By solving (5), the transitions probabilities can be found, given the probabilities p and λ. The probabilities p and λ are computed based on measured channel states using the estimates derived in [10].

To capture the joint spectrum occupancy, we consider the channel state probability, similar to (2) introducing λ_p as the conditional probability to have an occupied channel at point A, given the channel state atpoint B:

$$p = \mathrm{P}[x_n = 1], \quad \lambda_p = \mathrm{P}[x_n = 1 \mid \mathrm{y}_{n-1} = 1] \quad (6)$$

where and x_n and y_n are respectively the states probability for the two places.

Figure 4 shows the independent state probability p defined in (2) for each of the two points for 24 hours and a frequency bandwidth of 30 channels of 3 kHz each.

Figure 5 plot the two conditional probabilities λ_p (6) considering in turn x_n as the probability for place A and then B. The probability values for the two situations are quite similar.

The SO states of a number of adjacentfrequency channels at a given time instant can also be modeled as a two-state Markov chain of first order.

Based on this assumption, bidimensional SO can be computedas the probability that the k-th frequency channel to be free, given the probability that the adjacent (k-1)-the channel is free at the same time instant.

As extension of (6) in frequency domain for two places, joint SO probability can be defined as:

$$\mu_p = \mathrm{P}[x_{n,k} = 1 \mid \mathrm{y}_{n,k-1} = 1] \qquad (7)$$

where x and y have the same meaning as in (6) and the index n denotes the time and index k denotes the frequency channel.

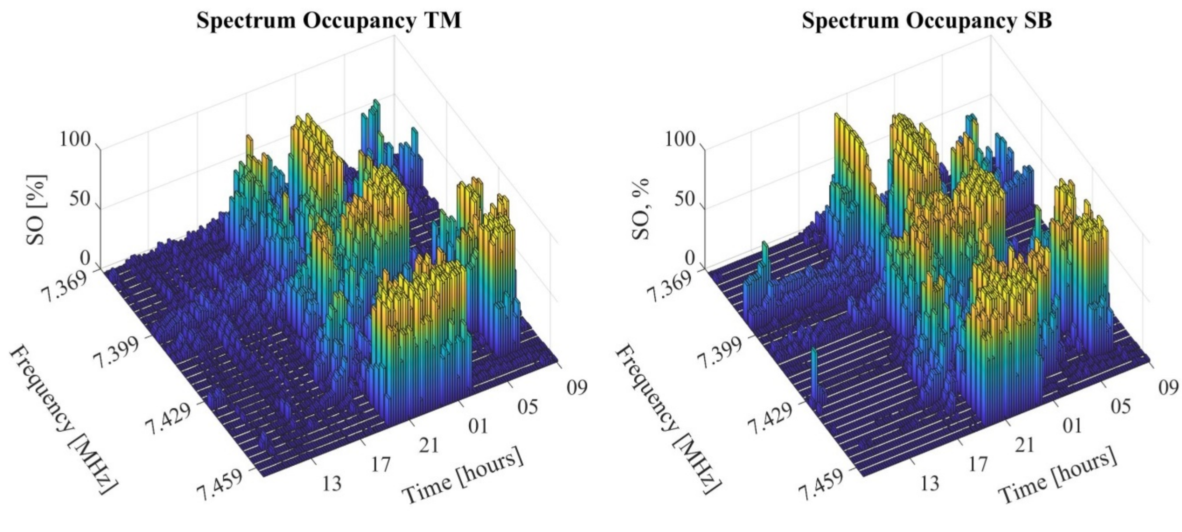

Figure 3: Simultaneous spectrum occupancy for the two locations

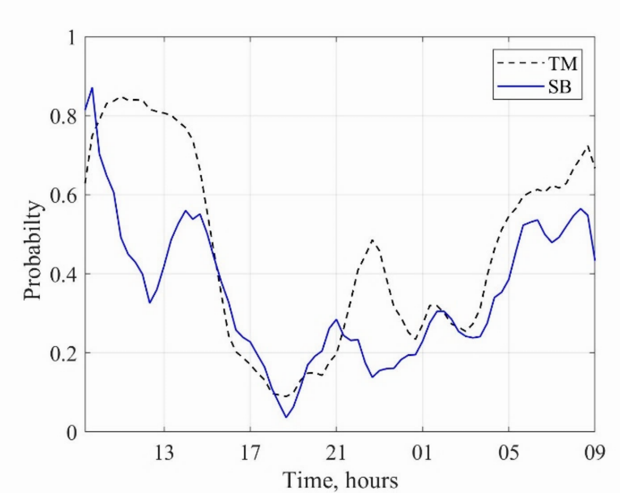

Figure 4: SO probability p for the two places – independent sampling

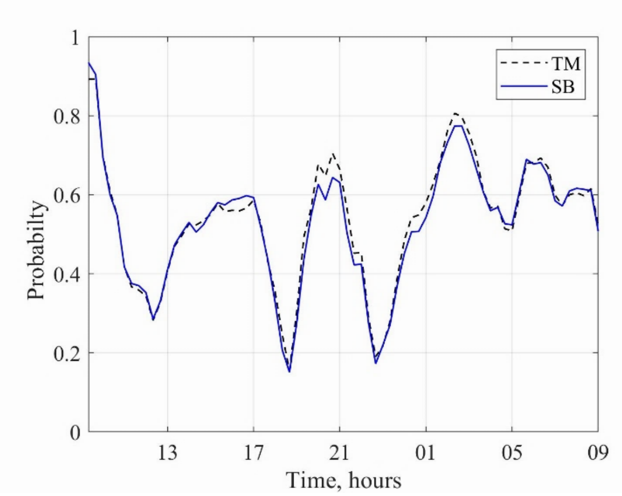

Figure 5: SO conditional probability for the two places

Figure 6 plots the frequency domain conditional probability for two different frequency bands. For comparison, figure 6 plots the time conditional probability too. It can be seen that the two probabilities are very close and could allow the characterization of the availability of a channel at a distant point, in time domain and at different frequencies, based on the local measured values.

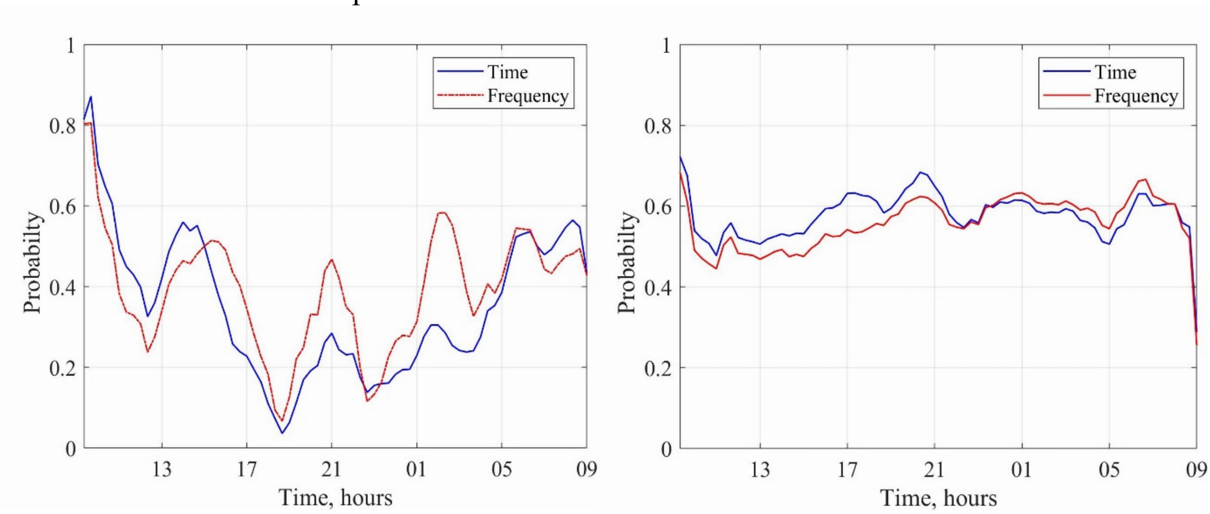

Figure 6: Comparative conditional probabilities in time and frequency for two frequency bands

4. Conclusions

The reported results prove the possibility of modelling the occupation state of a radio channel ata point based on local measurements using Markov models. Two different conditional probabilities have been defined: in time domain and in frequency domain.

The results have been validated through data based on real measurementsat two distant places, using identical SDR receivers and antennas.

Further, we intend an intensive measurement campaign to acquire a large data volume, on different frequency bands and longer time, to better characterise the joint statistics of the SO at two distant places. The report research has been motivated by application to Automotive industry.

Acknowledgements

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