HF Spectral Occupancy and azimuthal interference monitoring over the Eastern Mediterranean

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Abstract

High frequency (HF) spectral occupancy data collected by a dedicated measurement system installed in Cyprus are examined in order to demonstrate their importance to characterize the HF interference environment over the eastern Mediterranean region. An investigation into the main short-term temporal variability features of HF spectral occupancy based on low-elevation-angle omni-directional signal reception is presented. The importance of extending this investigation to explore the azimuthal HF interference is underlined in the context of radio-interference mitigation to support radio-communication systems operating in the HF spectrum.

1 Introduction

The HF channel is highly variable and unpredictable. It suffers from ionospheric phenomena that causes a variety of propagation impairments such as multipath, Doppler spread and deep fading. On the other hand, due to its long distance propagation characteristics, the HF spectrum is largely utilized around the globe. This results in a rather densely occupied spectrum. As a consequence, HF radio-wave systems experience limitations due to spectral congestion [1].
Studies of spectral occupancies in the past focused on frequency ranges corresponding to users of specific types (e.g. Broadcast users) [2] or related to specific applications (e.g. OTHR) [3].
In order to characterise the HF spectrum, past researchers [1] have made occupancy observations at HF and proposed an early definition of occupancy. Other studies reported in [4] covered HF spectral occupancy measurements in Europe since 1982, and given examples of models for the allocation congestion.
In 1981, systematic investigation of spectral occupancy over northern Europe started at UMIST involving only solstice measurements. The project gradually expanded, resulted in an extensive database over a complete sunspot cycle, which were reported in a number of papers and mathematical and AI models for spectral occupancy have been developed [4].
A few years ago, a dedicated measurement system has been established to provide effective measurement, analysis and modeling of HF spectral occupancy in Cyprus [5,6]. The system is capable of measuring the occupancy over the HF spectrum systematically on an hourly basis and has produced a substantial amount of occupancy data.

2 Measurement system and procedure

Measurement station having R&S EM 510 digital wideband receiver, is installed at a fixed location. The system is based on a R&S HE 016 antenna which is capable of receiving HF signals at both low and high incident angles. For signals having low-angle of arrival (most likely transmitted by distant transmitters), the active broadband omnidirectional monopole component of the antenna is employed whereas for signals emanating from predominantly high-angle trajectories (most likely transmitted by more localised transmitters), the omnidirectional turnstile component of the antenna is employed. Monopole and turnstile components of the antenna are switched in turn to the antenna input of the R&S EM 510 measurement receiver, and occupancy across each ITU defined frequency allocation is measured for signals received by both the antenna components.

The receiver is operated with a bandwidth of l kHz, and is, stepped through each ITU defined frequency allocation, spending 100 ms at each increment so that the whole HF band can be monitored in less than an hour. Each l kHz channel is defined as occupied at a particular field strength threshold (-20dBμV/m to 45dBμV/m in 5 dB steps) if the signal RMS value determined over the 100 ms observation period exceeds the corresponding calibration threshold set at the input to the receiver. The fraction of such channels across each user allocation then defines the congestion, Q for the particular field strength threshold and allocation using the particular antenna (Figure 1) [1].

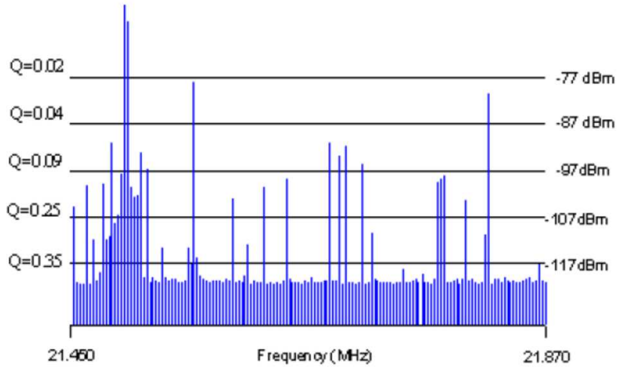

Figure 1. Congestion measurement within an ITU allocation.

3 Omnidirectional occupancy characteristics

Figure 2 shows the measured signal strength values of the entire HF spectrum at a particular time of day/night (00:00, 06:00, 12:00 and 18:00 hours). At midnight, due to reduced ionisation of the F layer, maximum usable frequency (MUF) is low due to the lack of ionospheric propagation support at higher frequencies. Therefore, we observe that the lower part of the spectrum is densely occupied.

In the early morning, as the ionisation of the F2 layer increases the MUF increases and some of the users tend to shift to higher parts of the spectrum (approx. 12-22 MHz) as evident in Figure 2 (b) to exploit the available spectrum.

At noon, to avoid D layer absorption of the signals in the lower part of the HF spectrum, even more users show a tendency to migrate to the upper part of the HF spectrum. Due to maximum ionisation the electron density of the F2 layer peaks and the MUF is maximum at noon. Therefore, almost the entire middle to upper part of the spectrum (i.e., 12-30 MHz) becomes usable, which is evident from Figure 2 (c).

Towards the evening, due to the reduction of MUF, users gradually migrate back to the lower part of the spectrum contributing to increased congestion as depicted in Figure 2 (d).

Figure 3 shows the measured interference signals received at low angle of elevation across a fixed/mobile user allocation ranging from 5.060-5.480 MHz. The bar chart below shows the state of channel occupancy at a threshold of 20 dBμV/m within the given allocation. The black bars indicate that the channels lying in that particular frequency slot is occupied and the white bars indicate unoccupied channels.

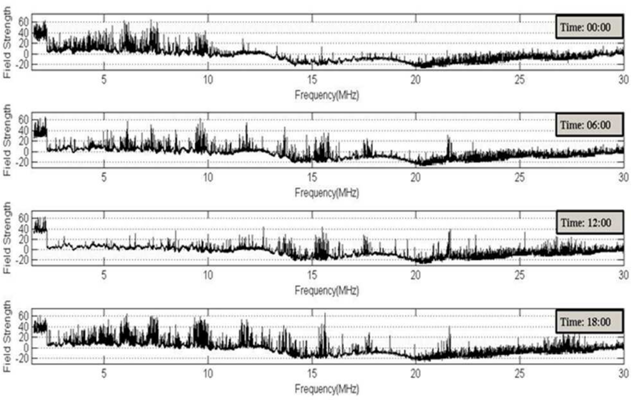

Figure 2. Hourly snapshots of the entire HF spectrum measured in Cyprus (a) at 00:00 hours (b) at 06:00 hours (c) at 12:00 hours and (d) at 18:00 hours.

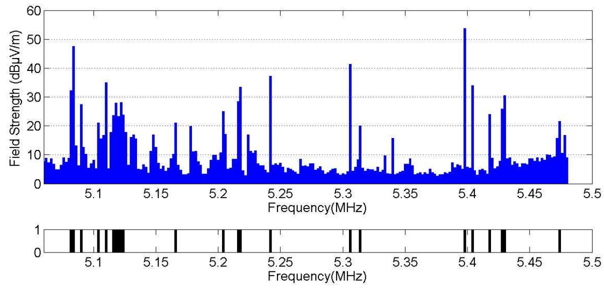

Figure 3. State of occupancy for 5.060-5.480 MHz, (a) field strength of interference signals (b) channel occupancy at a threshold 20dBμV/m.

Figure 4 demonstrates the diurnal profile of the HF spectrum occupancy (at a threshold of 20dBμV/m) which is in accordance to the HF spectrum snapshots presented in Figure 2. Around noon, the available window of operating frequencies is in the middle of the HF spectrum, whereas at night it shifts to the lower portion of the spectrum. This is due to the lack of ionospheric propagation support at higher frequencies, which limits the number of potential users that can operate. The high congestion problem at night is intensified due to the absence of ionospheric D-layer absorption allowing signals to travel longer distances thus causing greater co-channel interference. These factors impose the exploitation of a limited portion of the HF band which subsequently increases the level of occupancy within the available allocations. This problem is especially acute since the usable operating frequency window may be further limited during low solar activity periods. Spectral overlap causes high levels of occupancy at these times.

Allocations in the lower portion of the band exhibit different occupancy characteristics to those residing in the upper portion of the band. In the lower portion of the HF band occupancy peaks during the night. The variation in occupancy observed in allocations residing in the lower portion of the HF band follows the diurnal variation of circuit LUF (Lowest Usable Frequency) which is strongly dependent on D-layer absorption.

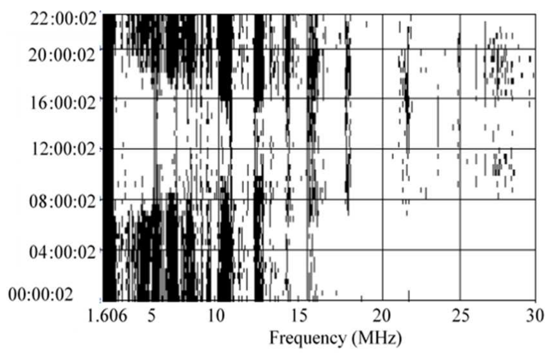

Figure 4. Diurnal plots of HF spectral occupancy at a threshold of 20dBμV/m.

Conversely, in the upper portion of the HF band a complete reversal of diurnal variation is observed which again shows significant diurnal variation, but in this case occupancy maximizes during daytime.

As well as being used for long range sky-wave communication, HF facilitates short range communication through near vertical incidence skywave (NVIS) propagation. For this mode, power is transmitted upwards and reflected by the ionosphere to give umbrella-like coverage. This mode is particularly important when the terrain does not permit ground wave communication. Because of the terrain imposed limitations, NVIS communication is particularly important for Cyprus. Typical frequency band for NVIS communication is 2-10 MHz. To investigate the effect of congestion on such NVIS links, we intend to analyse the high angle measurements obtained by turnstile component of HE016 antenna in the near future.

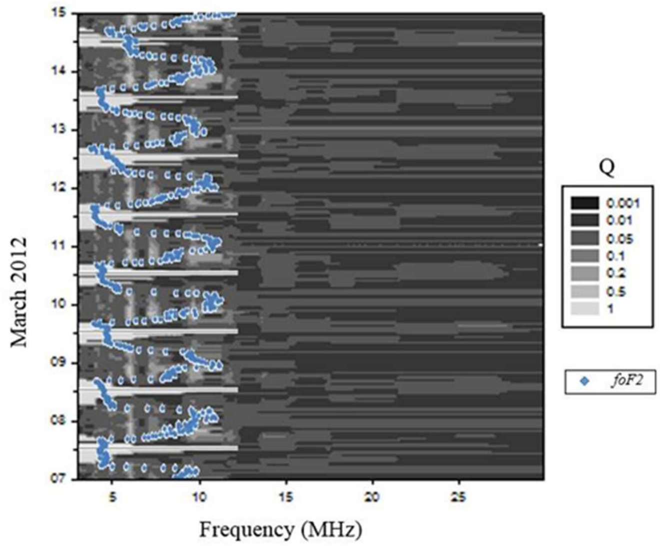

Figure 5. Weekly variation of spectral occupancy in the entire HF spectrum along with *foF2* variation.

Figure 5 displays the systematic day to day behaviour of HF spectral occupancy for seven consecutive days. The similarity of the occupancy pattern from day to day underlines the systematic and consistent way in which users are utilising the HF spectrum. It is also evident that the lower part of the spectrum up to 5 MHz is densely occupied during the night as indicated by the grayscale. As a result, NVIS propagation is going to be severely limited around this time of the night. The other part of the spectrum from 12-30 MHz exhibits lower congestion as expected based on the discussion in the previous section. To emphasize the effect of limited ionospheric propagation imposed by low ionisation during the night the variation of the critical frequency of the F2 layer, *foF2* is also superimposed on the same plot to mark the maximum possible frequency value for NVIS links. We note the minimum value of *foF2* at midnight, which is close to 3.5 MHz and maximum value around 12 MHz at noon. Clearly, at night the available frequency window is significantly reduced and as a result severe interference will affect any NVIS communication link.

As the HF spectrum usage is determined by the available frequency window over which ionospheric propagation is supported its long-term characteristics are determined by the seasonal and annual ionospheric variability which is defined by solar activity following roughly an eleven year cycle. As a result the upper and lower limit of this window exhibits not only diurnal but also seasonal and long-term characteristics. However presentation of these characteristics is beyond the scope of this paper which can be found in another study [7].

5 Azimuthal HF interference monitoring

Recent manual measurements on a limited time-scope in Cyprus have revealed that an important parameter that necessitates further examination is interference azimuth. In fact earlier work has been carried out on the azimuthal distribution of noise at a measurement site in southern England [8]. This showed that the greatest asymmetry in noise intensity was observed between the south-east and north-west, during 16-20 hours UT, at frequencies near 10 MHz, during spring and summer. Also, other researchers have reported measurements of the azimuthal distribution of HF interference at a site 40 km south of Paris, using an array of 32 biconical antennas [9]. Another long term study in southern England has indicated that interference is most severe for signals arriving from a south-easterly direction, with differences in congestion for east-west azimuths corresponding typically to a calibration threshold change of 10-20 dB [10]. Therefore our recent measurements coupled with these past studies indicate that the azimuthal distribution of HF spectral occupancy needs to be addressed by further systematic analysis and possibly this aspect has to be included in our model specifications. Results of measured and modelled azimuthal occupancy may be used to estimate interference, and select for a particular azimuth, ITU allocations in which there is an increased probability of finding interference free channels (at a specified threshold level) during a given period. As an example scenario, a possible use of the data and models may be in the choice of azimuth for establishing a link between a fixed station F and either a mobile station M or a choice of stations (A or B) of different relative azimuth to the fixed station as shown in Figure 6.

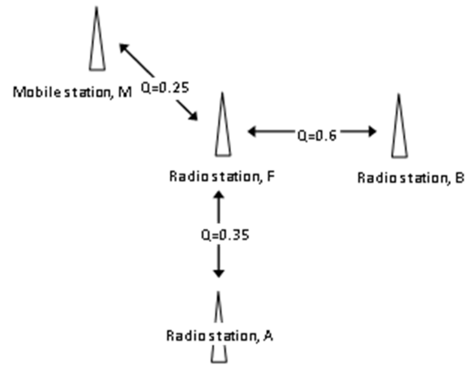

Figure 6. Example of selection of a link to a fixed station.

Another use of the data and models might be in the prediction of an optimum path on the basis of reduced interference. There may be the choice whereby a link can be established either directly with the desired station or indirectly via various available relay stations. An example is shown in Figure 7.

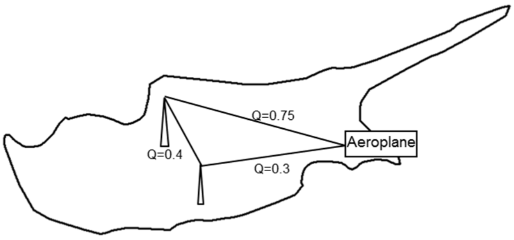

Figure 7. Example of combating interference via knowledge of azimuthal distribution of occupancy and selection of radio stations.

Suppose that all stations are within the range covered by an HF spectral occupancy model in Cyprus. An optimum link on the basis of reduced interference might not be the direct one. One may want to avoid a direct link to a station situated to the south-east relative to the transmitter, since interference is known to be highest in this direction. As an example, for ITU allocation 52 (Aeromobile) during, interference is estimated to be 0.75 for the south east link. For the indirect path interference is approximately 20 dB lower for an aeroplane in the region to the relay station, and 15dB lower for the link between the relay station and the station situated north.

6 Conclusions

The dedicated HF spectral occupancy measurement system of in Cyprus enables the extensive investigation of the dependence of HF interference characteristics on various parameters such as signal frequency, solar activity, filter bandwidth, time of day, season and signal elevation angle. The results and the analysis of observations from continuous monitoring of HF spectrum occupancy over Cyprus contribute towards improved understanding of HF spectral characteristics over the Eastern Mediterranean region and especially of any systematic variations present. The azimuthal occupancy studies in the near future could reveal specific directions that exhibit high interference, and therefore to enhance existing model specifications with a directional component. Such models combined with frequency predictions will find application by HF operators on typical interference occupancy levels and assist in the planning of frequency usage and management.

7 Acknowledgements

This paper is funded by the project "Extending HF Interference Studies over Cyprus" POST-DOC/0718/0149 which is co-funded by the Republic of Cyprus and the European Regional Development Fund (through the 'DIDAKTOR' RESTART 2016-2020 Programme for Research, Technological Development and Innovation).
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