2[nd] URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

Wideband Channel Availability Statistics over the High Frequency Spectrum in Cyprus

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Abstract

This paper investigates one-year measurement data (June 2012 to June 2013) from a dedicated HF spectral occupancy monitoring system installed in Cyprus to obtain the wideband HF channel availability statistics. For general applications, the percentage of free channels (4-kHz, 12-kHz, 18-kHz and 24-kHz) in every 1-MHz segment of entire HF spectrum (2-30 MHz) is determined. Channel availability percentage of the spectrum below maximum usable frequency (MUF) is also obtained particularly for NVIS applications, using the *foF2* data from Cyprus Digisonde (DPS-4D) Nicosia station. Results show that the overall channel availability decreases as bandwidth increases. Increased occupancy noted during morning and evening hours. The lack of lower frequency propagation during the daytime, corresponding increased use of these frequencies during the evening hours and wide availability of the higher frequencies are noticed. Typical availability of 6-kHz, 12-kHz, 18-kHz and 24-KHz channels have been quantified to be greater than 75% (best case) and below 50% (worst case).

***Index Terms*—ionosphere, spectral occupancy, wideband waveform, interference.**

1. Introduction

HF radio-wave systems experience limitations due to spectral congestion [1]. Co-channel and adjacent-channel interference from other users is often more important than man-made noise from incidental radiators, atmospheric noise from lightning, or galactic noise [2]. Since 1981, several measurement campaigns conducted around the globe to characterise and model HF spectral congestion. Studies reported in [3], [4], [5] encompass HF spectral occupancy measurements in Europe since 1982, and gave examples of models for ITU allocation congestion. In 1981, systematic investigation of spectral occupancy over northern Europe started at the University of Manchester Institute of Science and Technology (UMIST) concerning only solstice measurements [6]. The project progressively expanded, resulting in a wide-ranging database over a complete sunspot cycle, which were reported in a number of papers [4], [7] and mathematical models for spectral occupancy have been developed. Other measurement campaigns include, Central Australia from 1985 (as a part of Jindalee OTHR project) [8], Continental United States (CONUS) and Federal Republic of Germany (FRG) from 1987 [9], Sweden from 1990 [10] and Germany from 1993 [11] (as an extension of UMIST project), in Cyprus from 2012 [12], and in Canada from 2011 [13]. The measurements were used to characterise and model the narrowband HF channels from 1 to 3-kHz. Subsequently out of these studies several models have been developed following various approaches [14], [15]. In order to effectively share very limited spectrum (3-30 MHz), for many years, voice and low-speed data services in the HF radio bands have usually been restricted to channels not wider than 3-kHz. Due to the increasing demand for higher capacity and data throughputs regulatory communities had to consider breaking out of the long-standing 3-kHz channelization of the HF spectrum with considerable enhancement [16]. Several years' work resulted in wideband HF (WBHF) technology for radios. WBHF waveforms are capable of fully utilizing channels from 3-kHz up to 24-kHz, in increments of 3-KHz and can provide data rates from 75 bps up to 120 Kbps [17]. However, the employment of wideband signals has advantages if: (1) the HF medium can support the propagation; (2) the transmission does not interfere with other users in the band; and (3) the effects of external noise and interference can be mitigated through the use of appropriate signal processing.Three possible approaches have been outlined by Johnson et. al (2013), to meet the increasing demand of higher capacity and data throughput: the first is to increase data rates utilizing current 3-kHz allocations; the second is to increase data rates by using multiple 3-kHz contiguous or non-contiguous channels; and the third is by using wider contiguous bandwidth waveforms. Records of HF spectral occupancy are systematically being made by a dedicated fully automatic measurement system in Cyprus since 2009 [12] by automatically scanning the entire HF spectrum within an hour (approximately, 27 min for signals arriving at low and high angle of incidence, respectively). In this paper, one-year measurement data from June 2012 to June 2013 obtained from the mentioned system is investigated to obtain the wideband channel availability statistics. Although the dataset is not sufficiently dense to express the results in terms of CMA, yet two-fold investigations were conducted. These are as follows: First, for general applications, the percentage of free channels (6-kHz, 12-kHz, 18-kHz and 24-kHz) in every 1-MHz segment of entire HF spectrum (2-30 MHz) is determined and second, channel availability percentage of the spectrum below maximum usable frequency (MUF) is obtained particularly for near vertical incidence system (NVIS) applications, using the *foF2* data from Cyprus Digisonde (DPS-4D) Nicosia station.

2. Measurement System and Procedure

The measurement station is based on a digital wideband receiver and an active antenna system, consisting of two separate components capable of receiving HF signals at both low and high angle of incidence. For signals having low-angle of arrival (most likely transmitted by distant transmitters), the active broadband omnidirectional monopole component of the antenna system is employed whereas for signals emanating from predominantly high-angle trajectories (most likely transmitted by more localized transmitters operating in the near vertical incidence mode), the omnidirectional turnstile component of the antenna system is employed. Monopole and turnstile components of the antenna system are switched in turn to the antenna input of the measurement receiver, and occupancy across each ITU defined frequency allocation [1] is evaluated for signals received by both antenna components. The calibration of the two antenna components is controlled by a monitoring software, which manages the switching and the interchange of calibration settings for each of the two antenna components automatically. The receiver is operated with a bandwidth of 1 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 (approximately 27 min for signals arriving at low and high angle of incidence, respectively). Each 1 kHz channel is defined as occupied at a particular field strength threshold (20−45 dB·µV/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 [4] for the particular field strength threshold and allocation using the particular antenna. The scanning operations are repeated for all 95 allocations, taking approximately less than an hour. The entire process is repeated each hour for a 24 h period, resulting in a total of 95 allocations × 14 thresholds × 2 antenna components × 24 h = 63840 values of congestion. It is to be noted that under the measurement procedure described earlier, no distinction is made between man-made noise, natural noise, narrowband signals or wideband signals. We must also underline the fact that the adopted scheme of combining 1 kHz bins to estimate occupancy for user types other than broadcasting toward a general model could add to the uncertainty of the model and therefore such an extension would require further analysis.

3. Results and Discussion

3.1 Channel Availability across the Entire HF Spectrum

For wideband investigation, the band from 2 MHz to 30 MHz is divided into 1 MHz segments. Initial frequency bin resolution of 1 kHz is post-processed into 6-kHz, 12-kHz, 18-kHz, and 24-kHz bins. The sweep repeated approximately every 54 seconds. Measured receiver power was sorted and noise floor was calculated by averaging the 30 lowest values for each daily observation file processed in 1 MHz segments. For each 6-kHz, 12-kHz, 18-kHz, and 24-kHz bin, if the receiver power was 10dB above the noise floor it was considered occupied. Finally, the percentage of free channels is calculated for each 6-kHz, 12-kHz, 18-kHz, and 24-kHz bin and the results were displayed as 26 by 28 matrix for every one-day observation file. Figure 1 displays the 26 by 28 matrices derived from a single-day observation file. The values in the first column represents the consecutive scans at approximately 54-minute interval. Columns 2-29 displays the percentage of free channels at each 1-MHz segment from 2-30 MHz for all 26 scans along the day. The percentage values above 0.75 are coloured green. Values between 0.5 and 0.75, between 0.25 and 0.5, and below 0.25 are coloured yellow, orange, and red respectively. Overall channel availability decreases as bandwidth increases due to interferers, which leave less contiguous unused bandwidth. Increased occupancy is noted during morning and evening hours. Results show the expected time of day variations of channel utilization including the lack of lower frequency propagation during the day, and the corresponding increased use of these frequencies during the evening hours as well as wide availability of higher frequencies. As expected high availability noted for higher (non-propagating) frequencies. Overall 6-kHz results show higher than 75% availability during the day and 50% during the evening. 12-kHz results show a slight drop in availability with some evening segments below 50%. 18-KHz results illustrate further reduction in availability; however still considerable segments greater than 50%. 24-KHz results illustrate poor availability, the evening hours are far worse with many segments dropping below 50% availability. There is a clear diurnal variation in the percentage of free channels, which is evident from a sliced segment of consecutive 5-days observation displayed in Figure 2. It is clear that the percentage of free channels is more during day but rapidly falls during night. The impact of ionospheric dynamics on wideband channel performance can be understood by local characterization of ionospheric conditions. One of the most commonly utilized tools for measuring ionosphere profiles is vertical sounders called ionosondes, which analyze pulse echoes throughout the HF band to sample the vertical refractive profile up to the altitude of the peak density of free electrons. A modern digital ionosonde (DPS-4D) station is operating in Nicosia, Cyprus. We obtained the values of critical frequency of the F2 layer, *foF2* from manually scaled digital ionosonde measurements and used those as upper limit of the usable frequency spectrum particularly for NVIS applications. Figure 3 displays the state of the spectrum (‘occupied’ and ‘free’ fragments are indicated by ‘blue’ and ‘white’ colour respectively) below *foF2* at 12:00 hours for consecutive 5-days. We notice almost similar picture of on the first two days; *foF2* being 10 MHz and certain portions of the spectrum above 2 MHz and around 3, 5, 6.5, and 7.5 MHz are mostly congested. This pattern remains almost unchanged for the next three days and congestion prevails in same portions of the spectrum. However, primarily due to the reduction of *foF2* from 10 MHz to 8 MHz, the congested portion of the spectrum extends. The bar chart in Figure 4 displays the state of the spectrum below foF2 during 00:00, 06:00, 12:00 and 18:00 hours on the same day. It is noticed that the foF2 value is minimum (approximately 5.4 MHz) during 06:00 hours and maximum (approximately 9 MHz) during 12:00 hours. We also notice that greater portion of the usable spectrum experiences congestion during midnight, morning, and evening, whereas comparatively smaller portion is congested during day.

4. Conclusion

In this paper, we have quantified the percentage of availability for WBHF channels (6-kHz, 12-kHz, 18-kHz, 24-kHz) round-the-clock on an hourly basis. Results show that the % availability of contiguous 6-kHz channels is suggestive of implementing WBHF having multiple 3-kHz contiguous or non-contiguous channels. Use of wider contiguous bandwidth waveforms would experience severe congestion especially during night. We have also attempted to relate the ionospheric propagation conditions with the issue of other user interference particularly for NVIS applications. It is suggestive that the WBHF NVIS applications be implemented within frequency ranging from 5 to 10 MHz. It is expected that the results obtained from this research will help better understanding the channel interference issues in the wideband scenario and identify the appropriate portions of the HF spectrum for deployment of such channels in future.

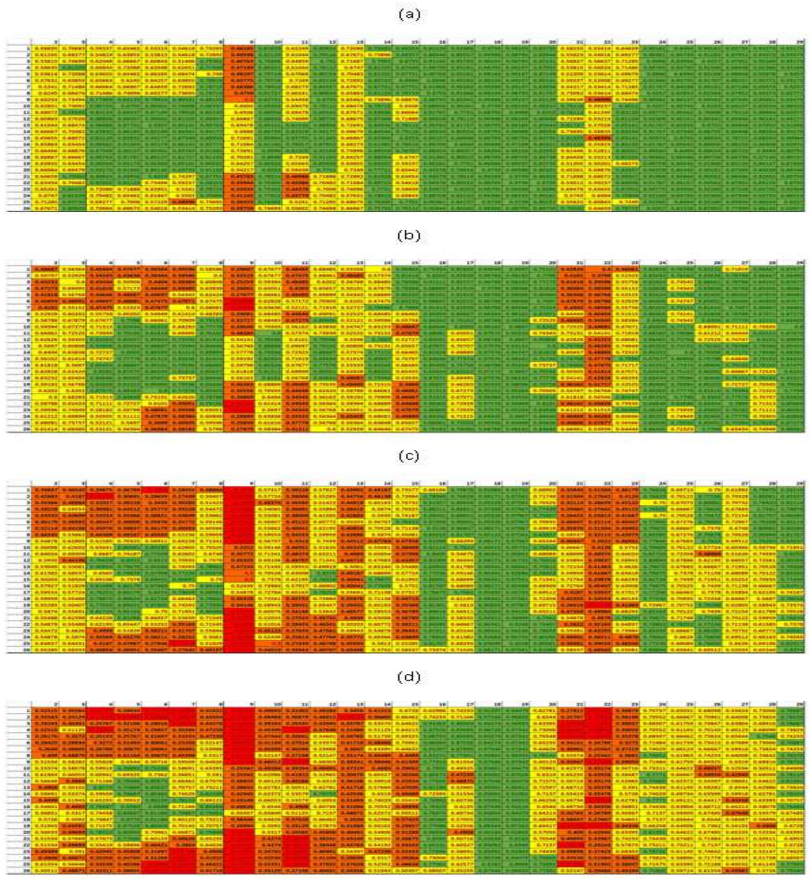

Figure 1. Free wideband channels in the 4 MHz segment: (a) 6-KHz, (b) 12-KHz, (c) 18-KHz, (d) 24-KHz.

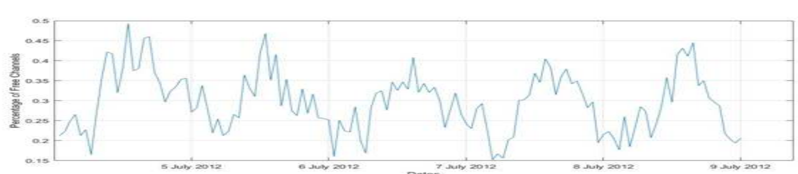

Figure 2. MUF limited 24-kHz wideband channel statistics for a sliced segment of consecutive 5-days.

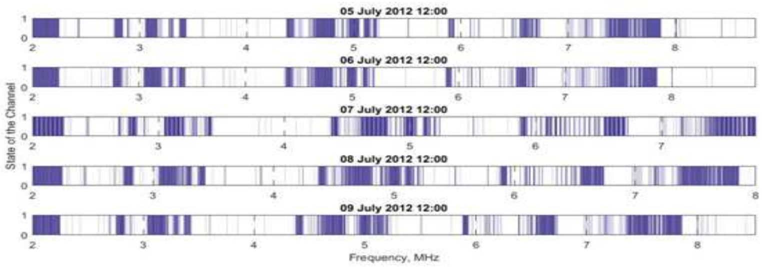

Figure 3. MUF limited state of the congestion at 12:00 hours in consecutive 5-days.

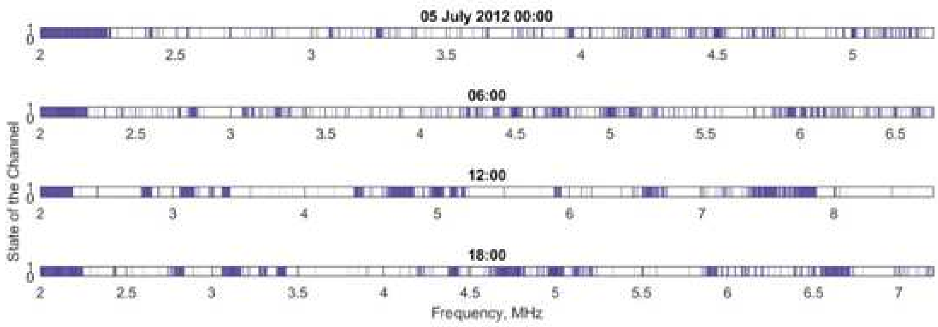

Figure 4. MUF limited diurnal state of the congestion at 00:00, 06:00, 12:00, and 18:00 hours on the same day.

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