Merging the Frequency Monitoring System with the Ionospheric Condition Monitoring System for Over the Horizon Radar

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Abstract

DRDC – Ottawa Research Centre is developing an experimental Over-the-horizon Radar (OTHR) with the potential for surveillance of the Canadian North. A Spectrum Management System (SMS) is a critical component of the OTHR, assessing the spectral environment and identifying portions of the High Frequency (HF) band of operation available for the system to use. In this report, the merging of two important sub-systems of the SMS, namely the merging of the Frequency Monitoring System (FMS) and the Ionospheric Condition Monitoring System (ICMS), was presented using a simulated commercial aircraft tracking exercise as a mission. The exercise involved tracking the Air China Flight CA990 commercial aircraft from New York's JFK International Airport to Beijing's Capital Airport, flying over Canada. Merging of the FMS and ICMS to form the SMS involves temporal matching and occupancy vector formatting before applying the Boolean function AND. The two main objectives of this experiment were met. The number of frequency channels available for this particular mission was determined for each 15 minute update. It was verified that options remained available over the full mission. The percentage of available frequency channels after merging the FMS and the ICMS over the entire spectrum varied from 0.35% to 1.07%. This mission exercise demonstrated that there is ample choice for OTHR transmitter operation and more options could be available by increasing ICMS frequency resolution. The ultimate goal is to have a real-time functional SMS capable of continuously managing the OTHR transmitter. Future work will include the design of a real-time SMS as well as the implementation of a communication channel with the OTHR transmitter.

Significance to Defence and Security

Persistent coverage and wide area surveillance of Canada's North using Over-the-Horizon Radar (OTHR) is being investigated as a potential technology for North Warning System replacement. The design of a spectrum management system demonstrate that the OTHR can operate within the frequency requirements set out by Industry Canada and that there is ample frequency channels available to allow for frequency agility. These capabilities are both critical for the adoption of this technology.

Résumé

RDDC Ottawa développe actuellement un radar transhorizon (OTHR) expérimental destiné à assurer éventuellement la surveillance du Nord canadien. Composante essentielle de l'OTHR, le système de gestion du spectre (SGS) évalue l'environnement spectral et y relève les portions de la bande des hautes fréquences (HF) qu'il peut exploiter. Le présent rapport fait état de la démonstration de la fusion de deux sous-systèmes importants du SGS, à savoir le système de surveillance des fréquences (SSF) et le système de surveillance des conditions ionosphériques (SSCI), dans le cadre d'un exercice simulant le suivi d'un aéronef commercial en tant que mission. L'exercice consistait à suivre l'itinéraire du vol CA990 d'Air China, de son point de départ, à l'aéroport international JFK de New York, à son point d'arrivée, à l'aéroport Capital de Beijing, en passant par l'espace aérien du Canada. La fusion du SSF et du SSCI pour constituer le SGS fait appel à l'appariement de données temporelles et le formatage de vecteurs d'occupation avant d'appliquer la fonction booléenne AND. Les deux grands objectifs de l'exercice ont été atteints. Le nombre de canaux de fréquences, disponibles pour les besoins de cette mission en particulier, a été déterminé à intervalles de 15 minutes. Il a été vérifié que des options demeurent disponibles tout au long de la mission. Le pourcentage de canaux de fréquences disponibles dans l'ensemble du spectre après la fusion du SSF et du SSCI variait de 0,35 à 1,07 %. Le présent exercice sous forme de mission a permis de démontrer qu'il existe amplement de canaux disponibles pour exploiter l'émetteur OTHR et que leur nombre pourrait être accru en augmentant la résolution en fréquence du SSCI. Le but ultime est de disposer d'un SGS en temps réel fonctionnel qui puisse gérer l'émetteur OTHR en continu. Les travaux à venir porteront sur la conception d'un SGS en temps réel et sur la mise en œuvre d'un canal de communication avec l'émetteur OTHR.

Importance pour la défense et la sécurité

Nous étudions la possibilité d'un radar transhorizon (OTHR) pour assurer la couverture constante et la surveillance à portée élargie du Nord canadien à titre de technologie potentielle pour remplacer le Système d'alerte du Nord. La conception d'un système de gestion du spectre a permis de montrer que l'OTHR peut être exploité selon les exigences en matière de fréquences qu'a établies Industrie Canada et qu'il existe amplement de canaux disponibles pour permettre l'agilité de fréquence. Ces capacités sont toutes deux essentielles à l'adoption de cette technologie.

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1 Introduction

Over-the-horizon Radar (OTHR) is capable of detecting targets at very long ranges in the thousands of kilometers [1]. DRDC Ottawa is developing an experimental OTHR with the potential for surveillance of the Canadian North. A Spectral Management System (SMS) is a critical component of the OTHR. A SMS incorporates different sensors to assess the spectral environment and to identify portions of the HF band of operation available for the system to use. In this report, results from the fusion of the Frequency Monitoring System (FMS) [2] and the Ionospheric Condition Monitoring System (ICMS) [3], to make up the SMS, are presented using a simulated commercial aircraft tracking exercise as a mission.

The ionosphere is a very unstable environment and conditions can change quickly and often. To identify the proper carrier frequency, waveform bandwidth, and elevation angle of the transmit signal required for a specified mission (i.e., range at which a target can be illuminated), ionospheric condition monitoring systems are used. To identify unoccupied frequency channels, frequency monitoring systems are used. For any mission, once the desired operational carrier frequency is known, it is important to verify that that particular frequency channel is available and unoccupied through real-time frequency monitoring. OTHR is not an allocated user of the High Frequency (HF) band but can operate in the band as long as it does not operate in frequency channels that have been allocated by Industry Canada for specific purposes such as broadcasting and distress and safety calling. OTHR also cannot interfere with other users in the band during operation.

In order to test the merging of the SMS and ICMS, a simulated tracking exercise of the Air China Flight CA990 commercial aircraft from New York's JFK International Airport to Beijing's Capital Airport, flying over Canada, was used as the mission.

In this report, the SMS is summarized in Section 2. The merging of the FMS and the ICMS is presented in Section 3. A summary, an analysis, and future work are provided in Section 4.

2 Spectrum Management System

As previously stated, a SMS incorporates different sensors to assess the spectral environment and to identify portions of the HF band of operation available for the system to use. The two main components of the SMS are the FMS and the ICMS. A FMS is required for OTHR to determine the unoccupied frequency channels available to operate the radar. Because it is not an allocated user of the HF band, the OTHR must operate without any interference to allocated RF services. Constant monitoring must be conducted to ensure that open and available channels are known at all times during operation. An ICMS is required for OTHR to provide desirable transmit signal carrier frequencies to maintain constant illumination of targets downrange [1]. Ionospheric plasma density changes over the course of the day, the night, and the seasons, as well as during other atmospheric events. The carrier frequency thus needs to be adjusted regularly to maintain that constant illumination.

In the following subsections, the FMS is summarized in Section 2.1 and the ICMS is summarized in Section 2.2.

2.1 Frequency Monitoring System

As was described in [2], the DRDC OTHR wideband FMS consists of data formatting of the receiver data for input into the FMS, impulse noise removal from sources such as regional lightning and local man-made sources, spectrum averaging for cleaner signals, thresholding to assign each frequency channel with an occupancy state, M of N filtering to refine the occupancy state of each frequency channel over a minute of time, and occupancy decision making to finalize the occupancy state of the scan. The output of the DRDC OTHR wideband FMS is a list of open and available frequencies and their corresponding bandwidth. For analysis provided in this report, the untested in-band frequency monitoring function of the FMS was not used due to issues not yet resolved in the testing equipment.

A 24 hour data collection session starting at 11:00 a.m. was conducted in August 16, 2015 at the OTHR receiver site, Area 6, using the reference monopole antenna as a receive antenna. The receiver used for data collection is the SDR-IP spectral receiver by RFspace [4]. Data are collected from the receiver using the SpectraVue software [5]. Unlike the experiment described in [2] where the data were collected and saved in a 2 byte binary format file containing a 1024 bytes header followed by power spectra at a rate of 30 per seconds., this 24 hour data collection session saved data as entire FFT data values in a .CSV Excel Format. The first row of data consists of comma separated data representing the frequency of each FFT bin in Hertz. The second and subsequent rows consist of amplitude information in dB for each FFT bin.

The frequency range was set between 2 MHz and 22 MHz with 1.22 kHz resolution. In total, 732478 power spectra were collected, which produced 16384 sample points per spectra. Amplitude units are in dBm. Formatting of the data involved reading each spectrum one at a time. Because of the large file size, data were saved in a 32400x16384 matrix, representing over an hour of recorded data. The calculated rate of spectra per second was 8.5, meaning that it took slightly longer than a second to get nine spectra recorded. For this experiment only, it was decided to use the nine spectra to average per second in the code, even though in real life, it was slightly greater than one second of recorded data. For real-time operations, this is unacceptable since a small amount of time is essentially lost with every averaging operation, which over time, becomes a major issue. Data collection will be revisited at a later time in order to resolve this issue, perhaps returning to the original recording format of a 2 byte binary format file. The timing issue will be resolved at a later time. One cycle of wideband occupancy processing requires one minute of collected data for accurate frequency channel occupancy determination. For this case, that is equivalent to 540 spectra—nine spectra per second multiplied by sixty seconds.

The FMS described in [2] was used to process and analyze the latest data. Results are presented in this sub-section. The availability state vector for one spectrum averaged over one second, after the estimated noise floor is subtracted from the averaged spectrum, is shown in Figure 1. The number of vacant channels is 7578 over the 16384 spectrum data points, giving an availability rate of 46.25% for frequency amplitudes below the 6 dB threshold. A histogram of the respective bandwidths of each available frequency channel is shown in Figure 2. Bandwidth variations between 0 kHz and 45 kHz of frequency amplitudes below the threshold of 6 dB is observed. Considering the spectrum averaged 9 spectra in one second, it is still considered quite noisy. Further averaging of each frequency channel in the subsequent steps of the FMS is expected to increase the availability of available frequency channels. The minimum bandwidth required to determine a band of frequencies is available can be varied in the code. Current forecast indicates minimum bandwidths varying between 10 kHz, 20 kHz, and 40 kHz, depending on the transmit signal waveform requirements. The analysis of channel availability for these three minimum bandwidths was conducted for one minute of data collection.

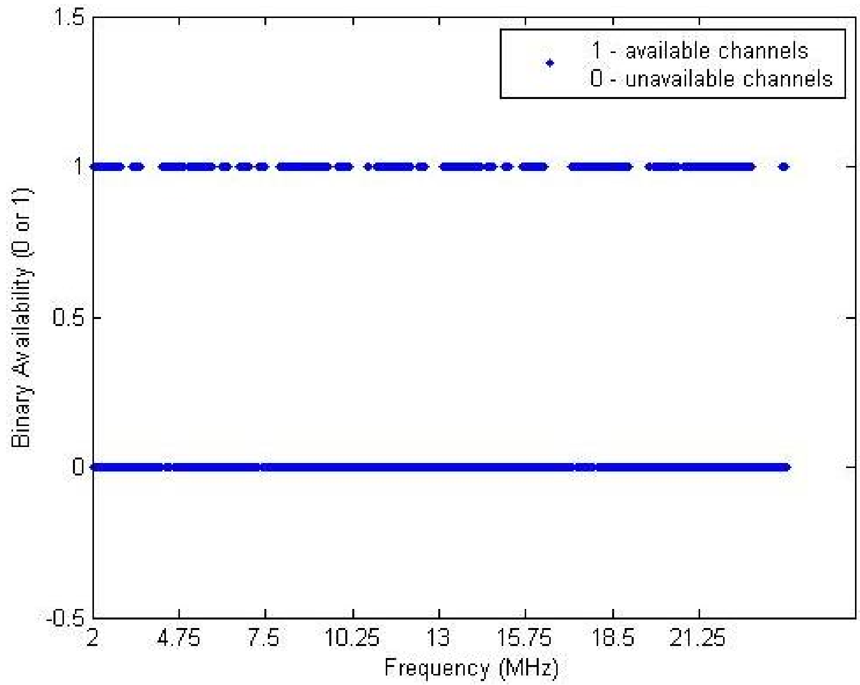

Figure 1: *Availability state vector for 1 second of data. A value of one signifies available and a value of 0 signifies unavailable.*

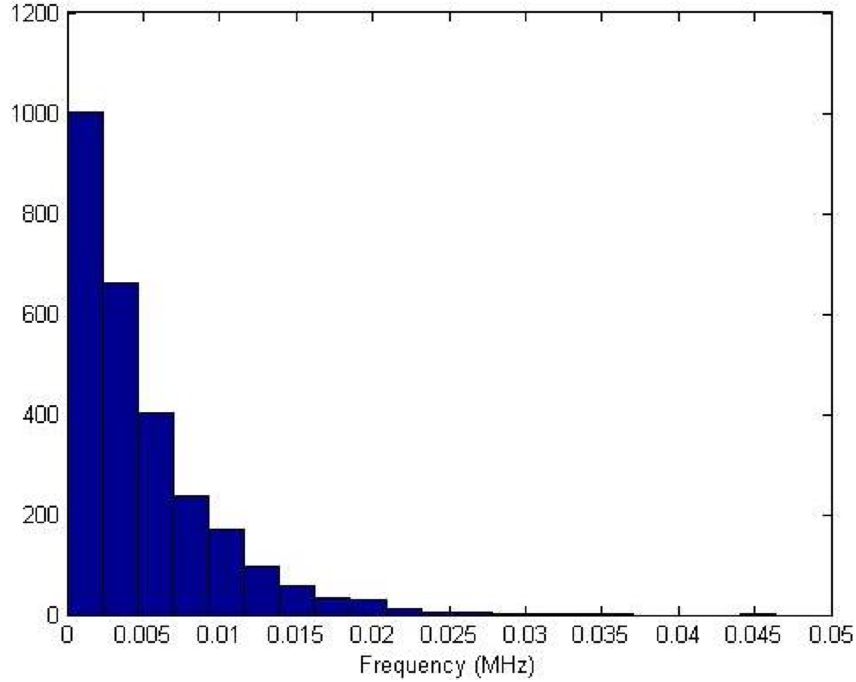

Figure 2: *Bandwidth histogram of all available frequency channels for one second of data.*

For M of N filtering, the N value represents the total number of exemplars and M represents the minimum number of occupancy values of 0 required in order to declare that frequency channel unoccupied and available. N was chosen to be sixty to represent 60 seconds of data. M was chosen to be thirty, meaning that for every frequency channel, the availability state vectors need to be unoccupied more than 50% of the time in order to declare that frequency channel available.

The availability state vector for one spectrum averaged over one minute, after M of N filtering when using 10 kHz, 20 kHz, and 40 kHz as the minimum bandwidth required to declare a channel available, is shown in Figure 3, Figure 5, and Figure 7, respectively. The number of vacant channels using 10 kHz as the minimum bandwidth required to declare a channel available is 9115 over the 16384 spectrum data points, giving an availability rate of 55.63%, which shows a 9.38% increase in availability over the availability state vector for one spectrum averaged over one second. When using 20 kHz as the minimum bandwidth, the number of vacant channels is 8665 over the 16384 spectrum data points, giving an availability rate of 47.12%. When using 40 kHz as the minimum bandwidth, the number of vacant channels is 7693 over the 16384 spectrum data points, giving an availability rate of 46.95%.

A histogram of the bandwidths of each available frequency channel for all three scenarios (10 kHz, 20 kHz, and 40 kHz) is shown in Figure 4, Figure 6, and Figure 8, respectively. For the 10 kHz bandwidth case, available bandwidth varies between 12.2 kHz and 494 kHz. That is a factor of 10 greater than the available bandwidth observed for one second of data. Averaging and M of N filtering allow for more frequency channels to be declared available and ready to be used by the OTHR. For the 20 kHz and 40 kHz bandwidth cases, the same results are obtained except that the frequency channels with lower bandwidth availability no longer get classified as available. Even so, there are still plenty of available frequency channels to use for the OTHR project with the higher minimum bandwidth requirement.

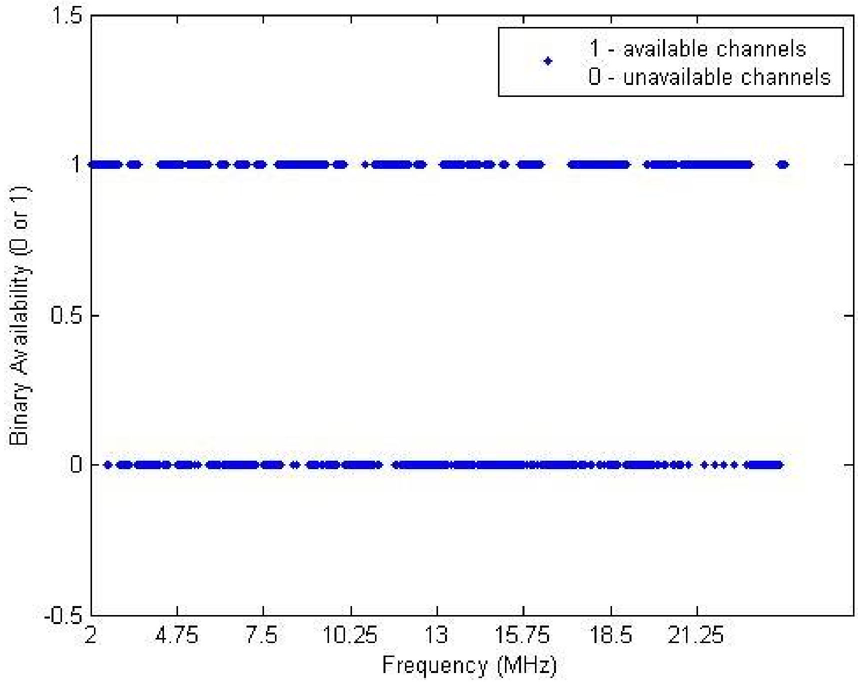

Figure 3: *Availability state vector for one minute of data using 10 kHz as the minimum bandwidth required to declare a channel unoccupied.*

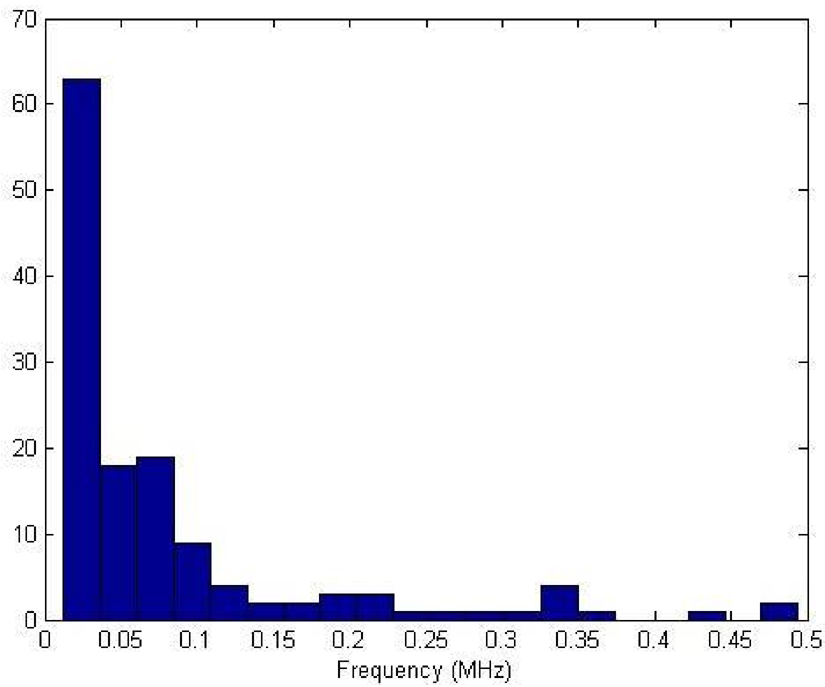

Figure 4: *Bandwidth histogram of all available frequency channels for one minute of data using 10 kHz as the minimum bandwidth required to declare a channel unoccupied.*

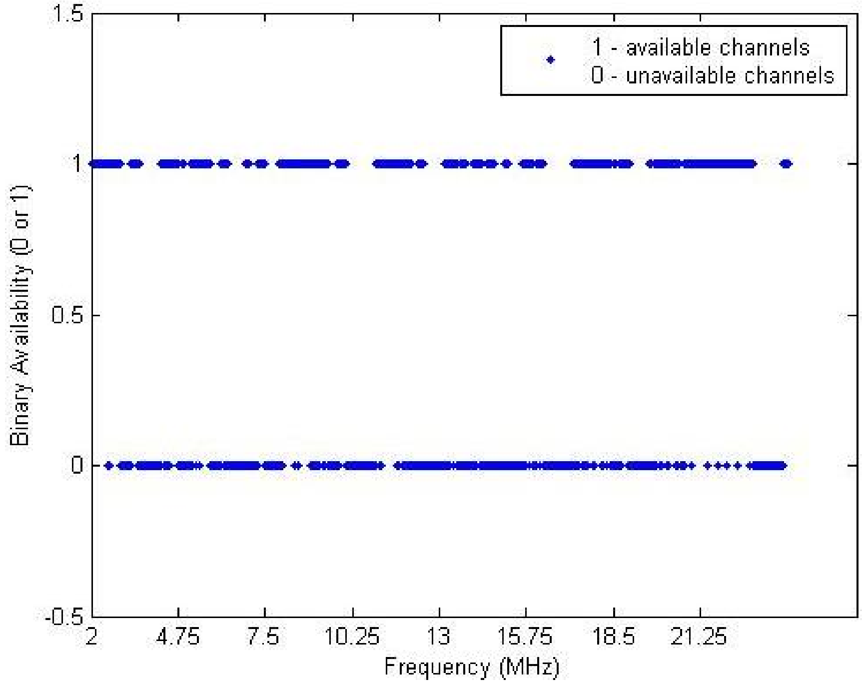

Figure 5: *Availability state vector for one minute of data using 20 kHz as the minimum bandwidth required to declare a channel unoccupied.*

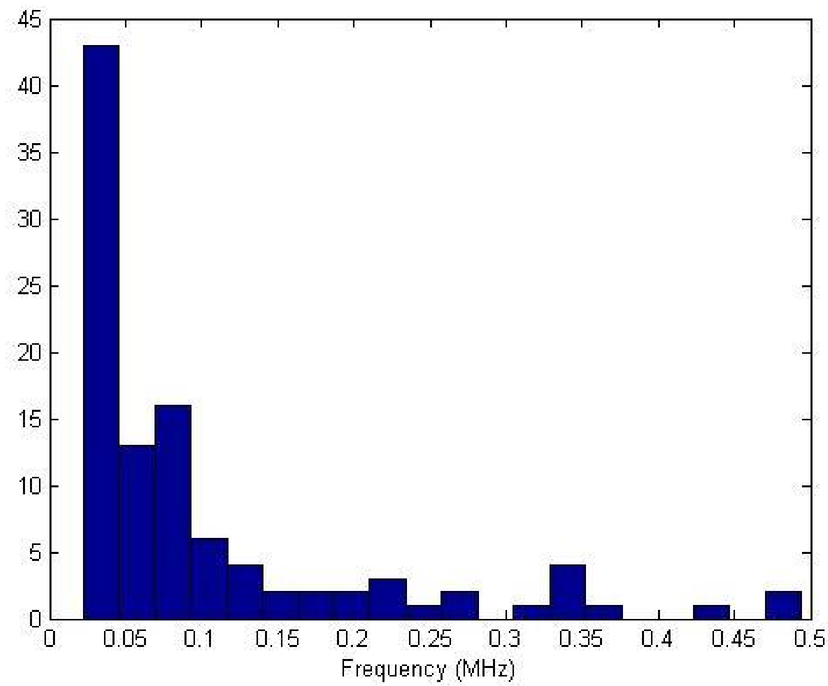

Figure 6: *Bandwidth histogram of all available frequency channels for one minute of data using 20 kHz as the minimum bandwidth required to declare a channel unoccupied.*

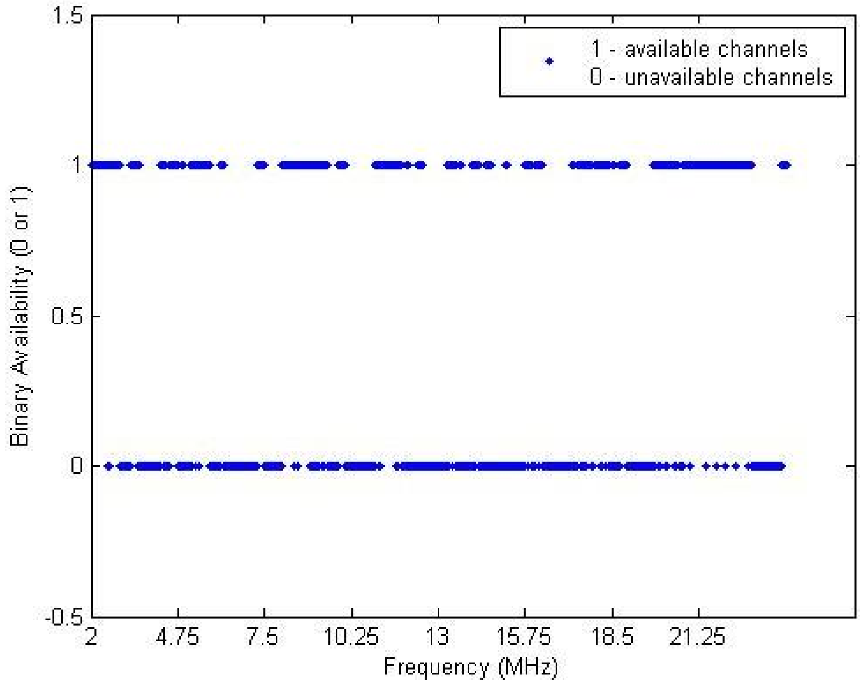

Figure 7: *Availability state vector for one minute of data using 40 kHz as the minimum bandwidth required to declare a channel unoccupied.*

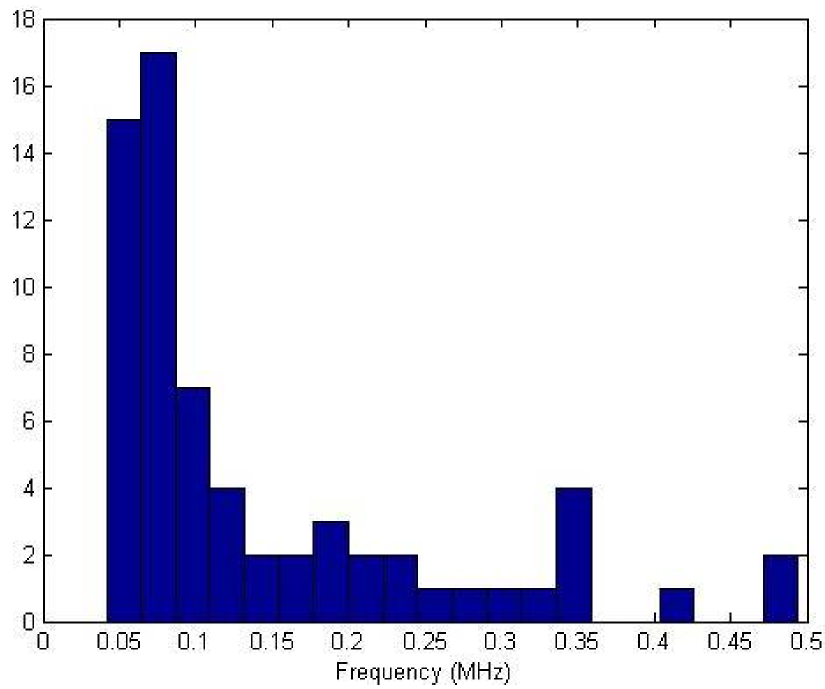

Figure 8: *Bandwidth histogram of all available frequency channels for one minute of data using 40 kHz as the minimum bandwidth required to declare a channel unoccupied.*

A time history was produced showing the channel availability over 24 hours of data recorded at a one minute update rate with a minimum bandwidth required to determine a band of frequencies is available of 10 kHz, 20 kHz, and 40 kHz. Though a one second update rate using a moving window is possible after the first minute of data collection, it was deemed too computationally costly to process at this time. This is because all of the data collected over 24 hours is being processed offline at once. The time histories are shown in Figure 9, Figure 10, and Figure 11. Time zero in the figure relates to 11:00 EST. Data points in white represent available frequency channels and data points in black represent occupied frequency channels. Changes in frequency availability over time are discernible in all three cases with more availability during daytime versus nighttime. The wide black vertical bands seen across the entire 24 hour span are mostly frequency bands that OTHR is restricted from using as per Industry Canada requirements. Even though those restricted channels might become available, we are barred from using them; therefore, they are always assigned as unavailable.

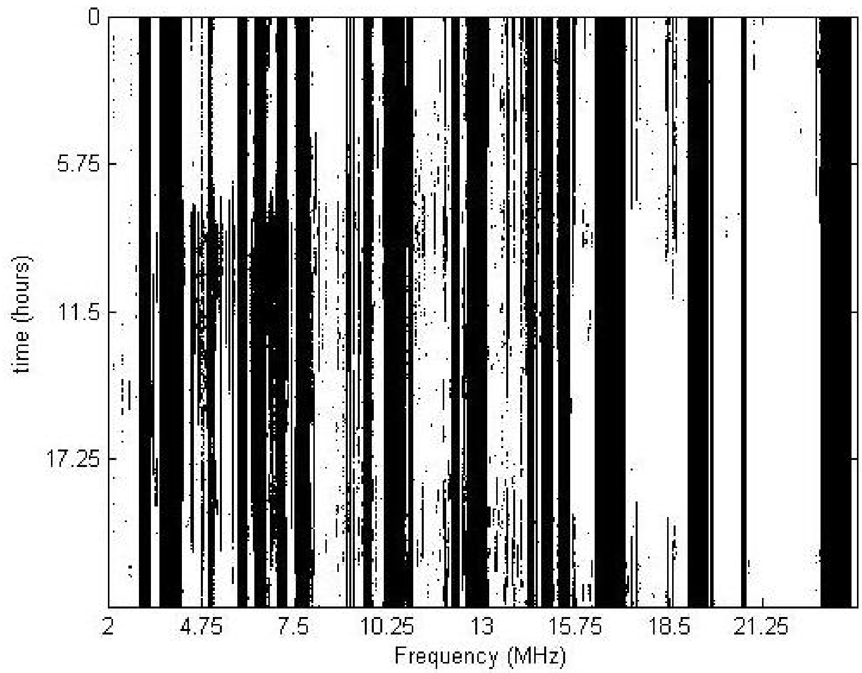

Figure 9: *Availability result over 24 hours at 1 minute update rate (white areas signify available channels and black areas signify unavailable channels) using 10 kHz as the minimum bandwidth required to declare a channel available.*

Once the channel availability was determined, the available transmit signal centre frequencies to operate the OTHR were calculated. This process required eliminating half the minimum bandwidth required to determine a band of frequencies is unoccupied, at each end of the unoccupied band, as shown in Figure 12. A time history was produced showing the centre frequency availability over 24 hours of data recorded at a one minute update rate with a minimum bandwidth of 10 kHz, 20 kHz, and 40 kHz. The time histories are shown in Figure 13, Figure 15, and Figure 17, respectively. The percentage of available frequency channels over the whole spectrum over 24 hours was calculated over each case. The results are presented in Figure 14, Figure 16, and Figure 18, respectively. There is a noticeable drop in frequency channel availability in the evening, about a 10% drop from availability during the afternoon. Peak availability occurs early in the morning, between 2 a.m. and 4 a.m.

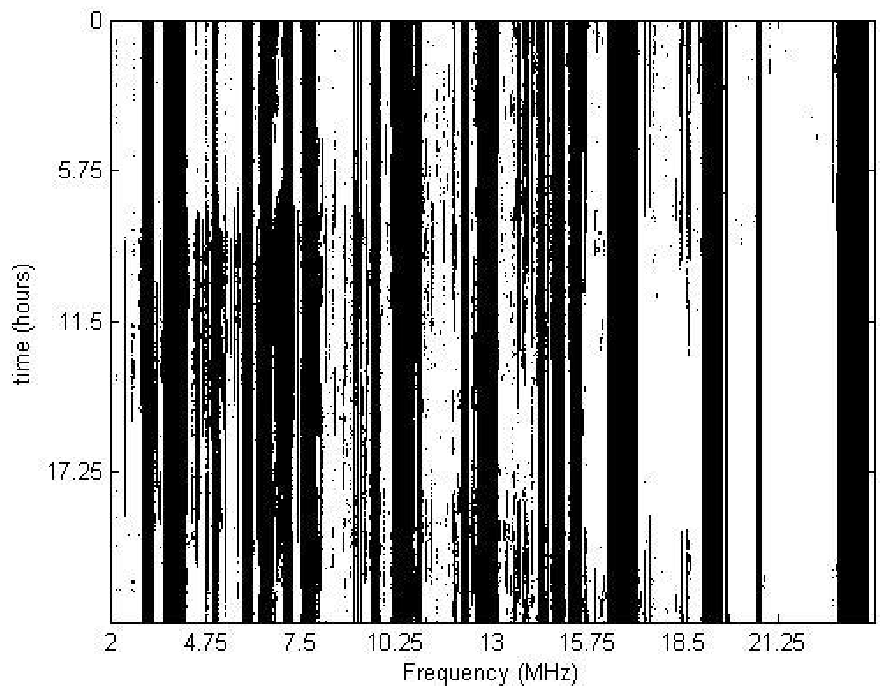

Figure 10: *Availability result over 24 hours at 1 minute update rate (white areas signify available channels and black areas signify unavailable channels) using 20 kHz as the minimum bandwidth required to declare a channel available.*

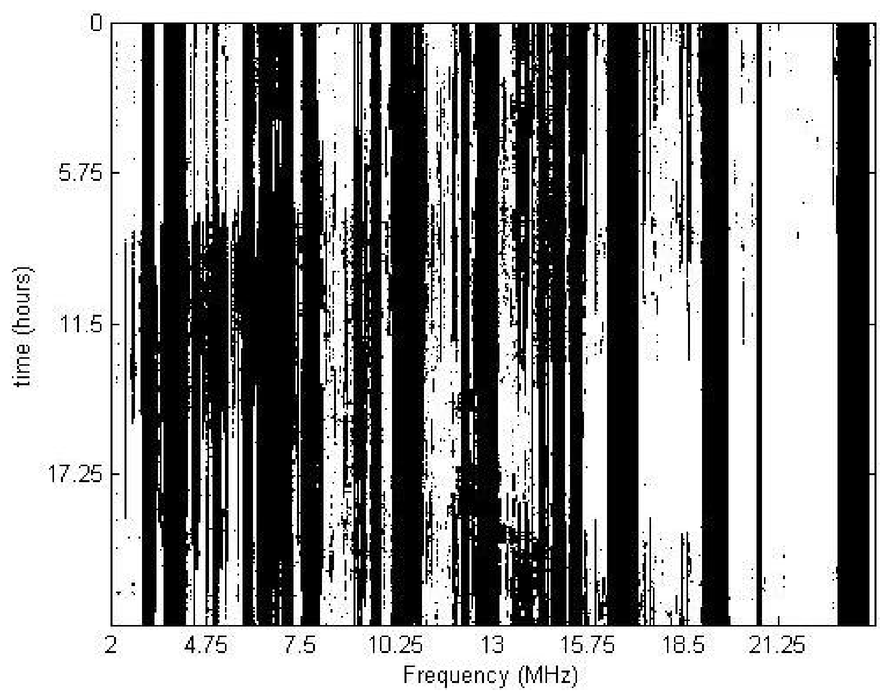

Figure 11: *Availability result over 24 hours at 1 minute update rate (white areas signify available channels and black areas signify unavailable channels) using 40 kHz as the minimum bandwidth required to declare a channel available.*

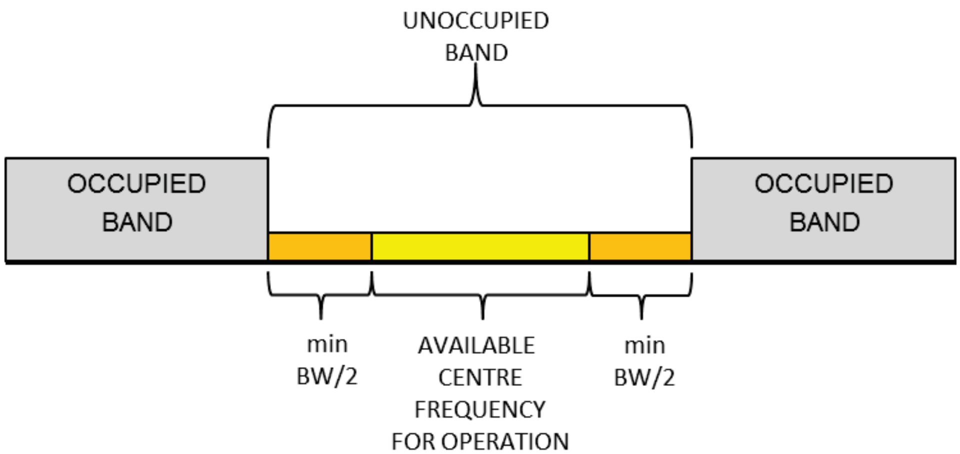

Figure 12: *Schematic of how available transmit signal centre frequencies are calculated.*

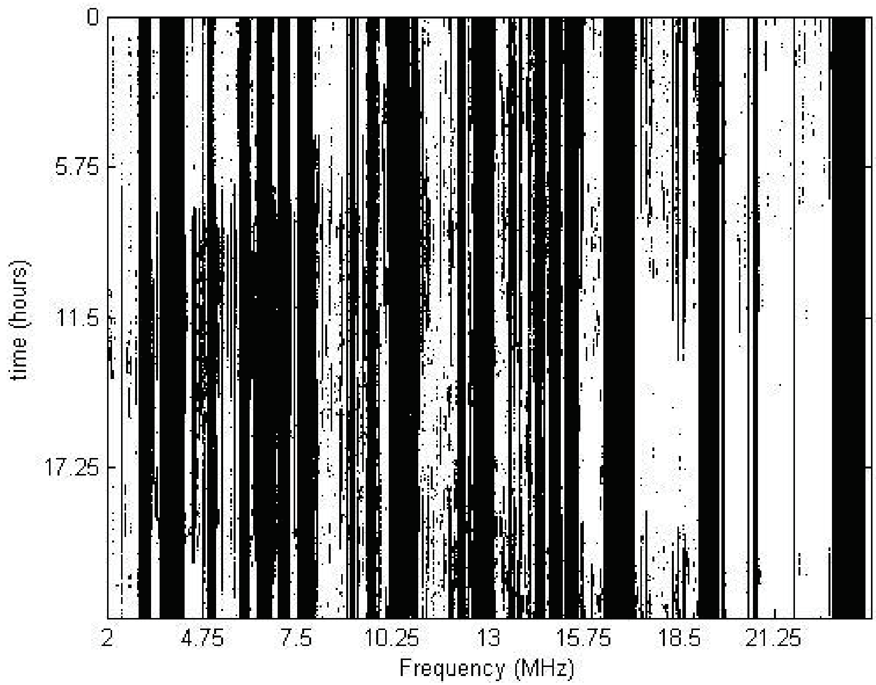

Figure 13: *Transmit signal centre frequency availability result over 24 hours at 1 minute update rate (white areas signify available centre frequency channels and black areas signify unavailable centre frequency channels) using 10 kHz as the minimum bandwidth required to declare a channel available.*

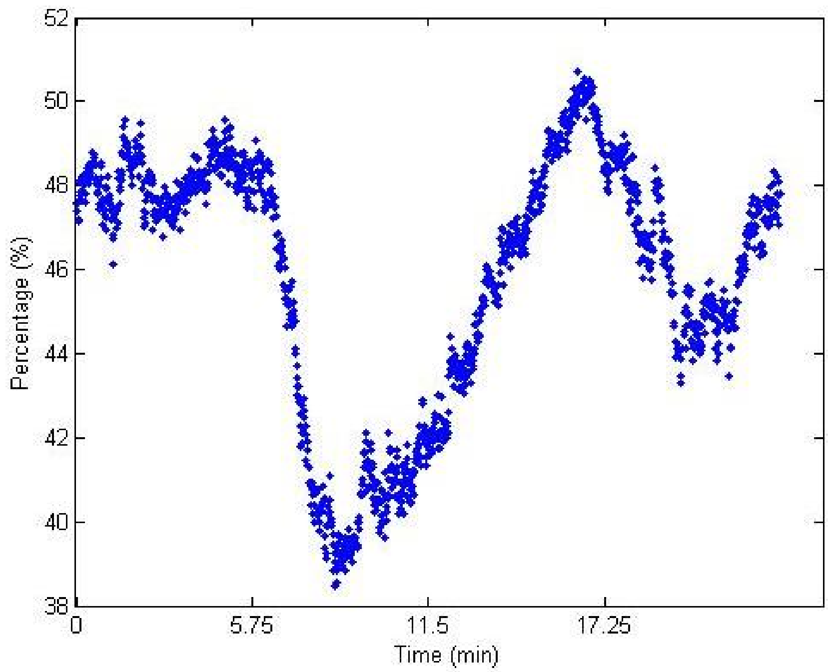

Figure 14: *Percentage of available frequency channels over 24 hours using 10 kHz as the minimum bandwidth.*

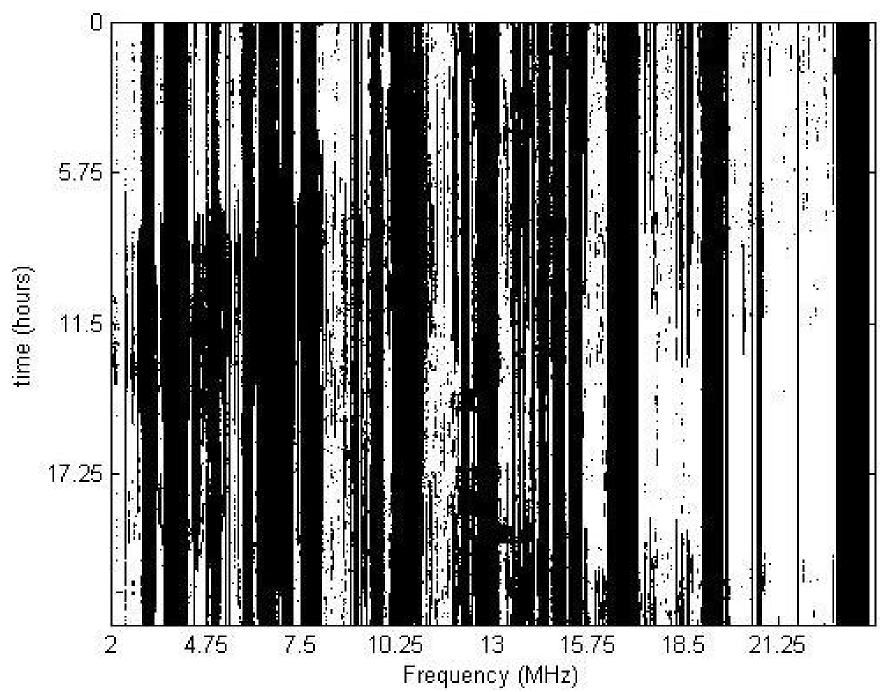

Figure 15: *Transmit signal centre frequency availability result over 24 hours at 1 minute update rate (white areas signify available centre frequency channels and black areas signify unavailable centre frequency channels) using 20 kHz as the minimum bandwidth.*

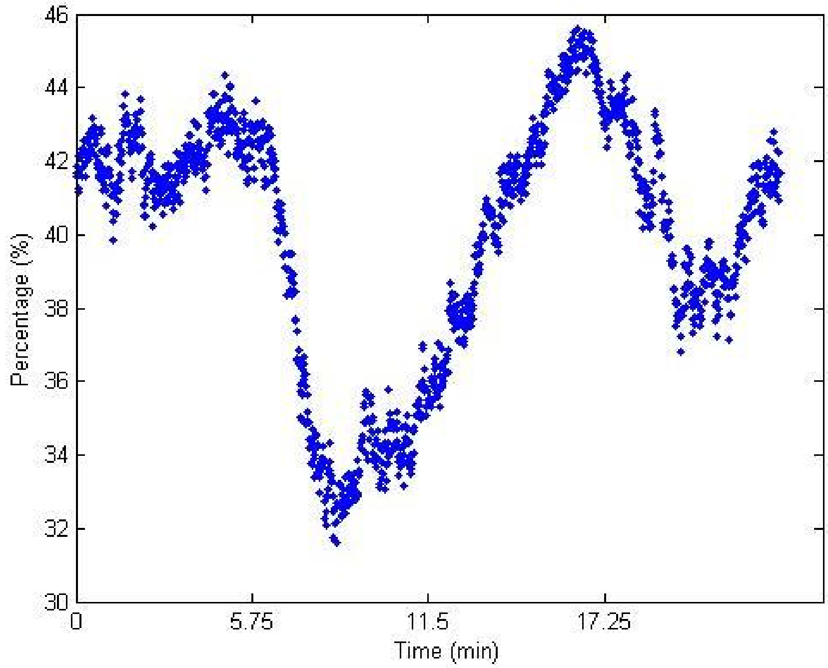

Figure 16: *Percentage of available frequency channels over 24 hours using 20 kHz as the minimum bandwidth.*

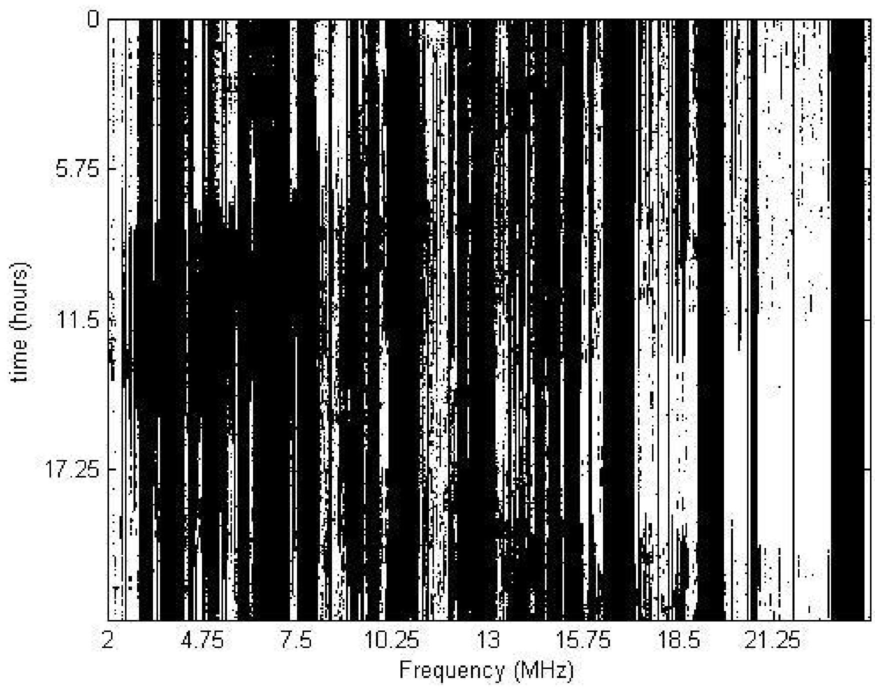

Figure 17: *Transmit signal centre frequency availability result over 24 hours at 1 minute update rate (white areas signify available centre frequency channels and black areas signify unavailable centre frequency channels) using 40 kHz as the minimum bandwidth.*

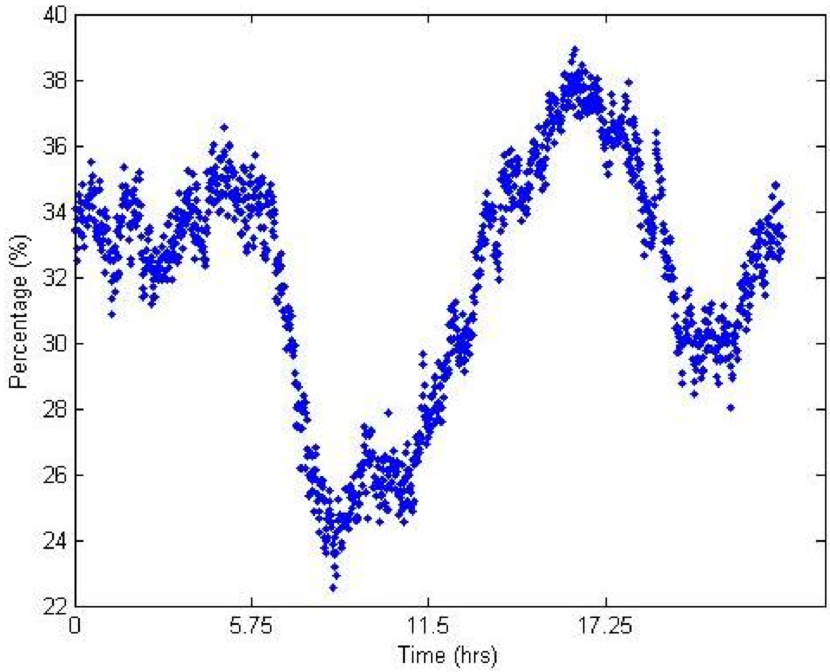

Figure 18: Percentage of available frequency channels over 24 hours using 40 kHz as the minimum bandwidth.

The length of time a frequency channel remains available is an important parameter that helps prioritize available centre frequencies for a given mission. The percentage of time a frequency channel was available over 24 hours was calculated over the available spectrum with a minimum bandwidth of 10 kHz, 20 kHz, and 40 kHz. The results are presented in Figure 19, Figure 20, and Figure 21, respectively. It can be observed that there are several frequency channels that are available for most of the day. For instance, 35.62% of the frequency channels are available 80% or more of the time with a minimum bandwidth of 10 kHz, 27.78% of the frequency channels are available 80% or more of the time with a minimum bandwidth of 20 kHz, and 19.17% of the frequency channels are available 80% or more of the time with a minimum bandwidth of 40 KHz.

The choice of which frequency channel to use from a list of available values comes down to the mission at hand. In the next section, an explanation of the atmospheric condition monitoring is provided as well as a description of a mission used to test the merging of both monitoring systems.

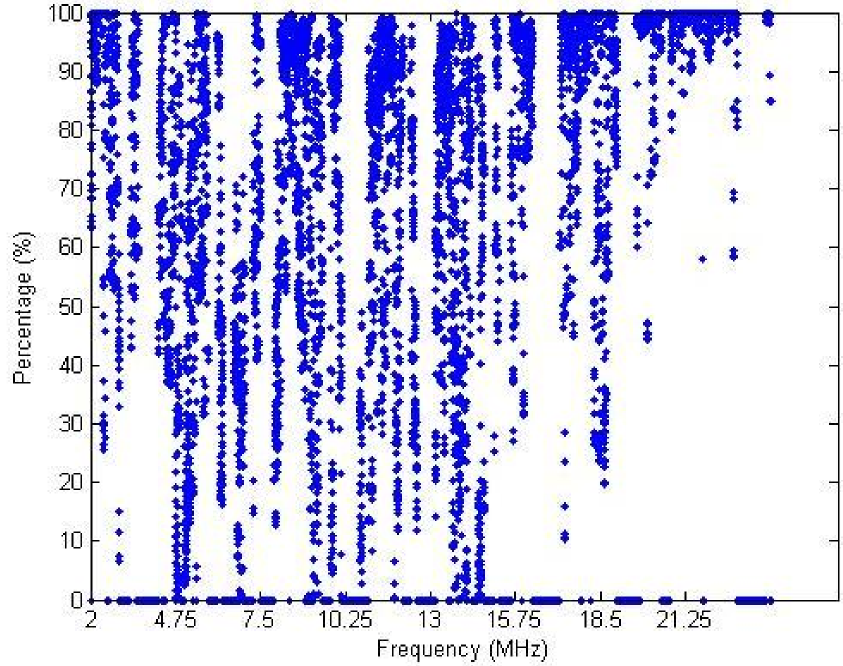

Figure 19: *Percentage of time frequency channels is available over 24 hours using 10 kHz as the minimum bandwidth.*

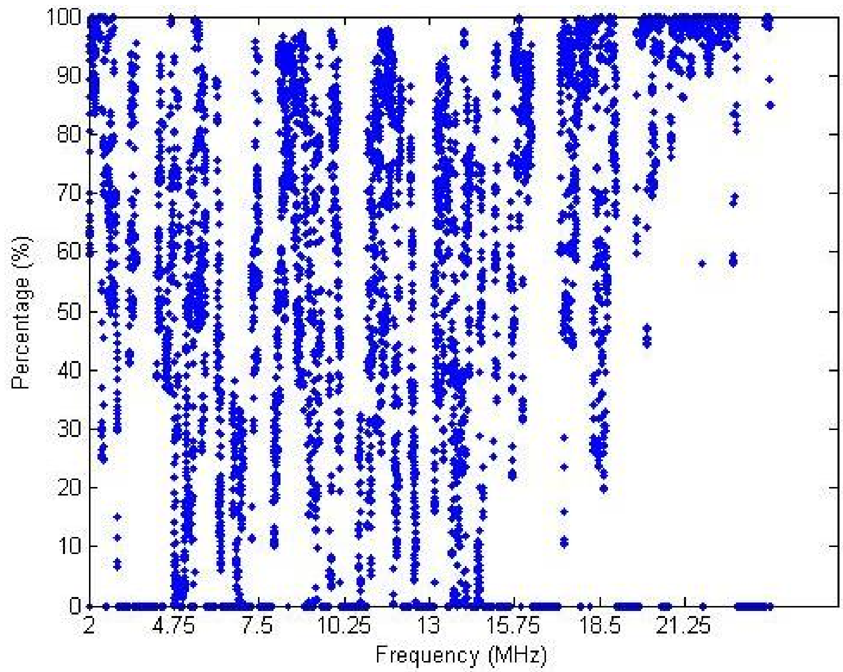

Figure 20: *Percentage of time frequency channels is available over 24 hours using 20 kHz as the minimum bandwidth.*

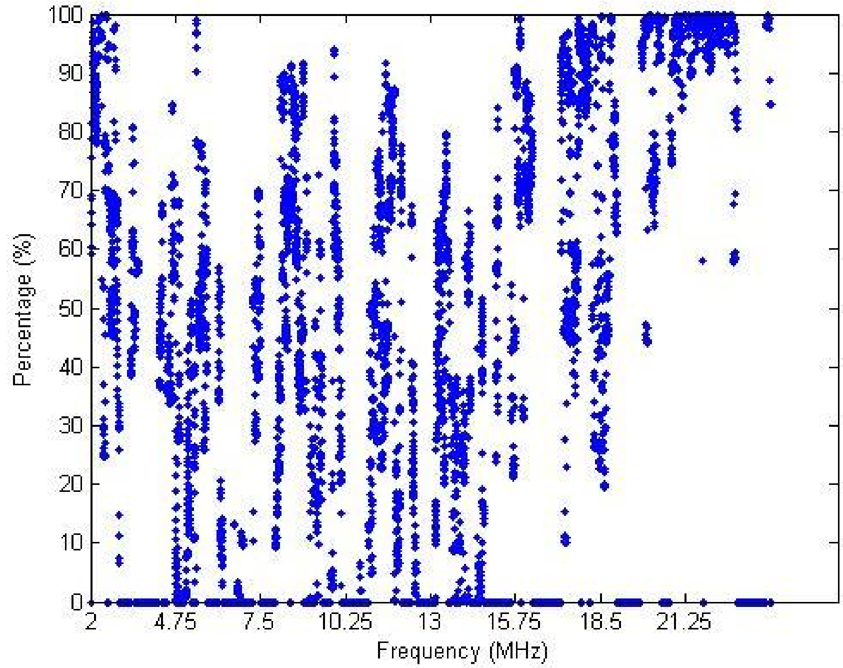

Figure 21: *Percentage of time frequency channels is available over 24 hours using 40 kHz as the minimum bandwidth.*

2.2 Ionospheric Condition Monitoring System

OTHR systems operate by reflecting signals from the bottom of the earth's ionosphere to achieve the illumination of targets to a range of at least 3,000 km. The ionosphere is a plasma layer at an altitude of approximately 300 km, consisting of ionized nitrogen and oxygen. The ionization density rises and falls over the course of the day and night in response to the level of ultraviolet radiation from the sun [6]–[14].

For OTHR systems, the carrier frequency required to illuminate a fixed position downrange of the radar is, roughly speaking, positively correlated with the ionospheric plasma density. Thus the radar operator must adjust the carrier frequency regularly to maintain illumination of the required downrange locations. Furthermore, the operator must contend with the issue that OTHR is not an allocated radiofrequency service and thus must only operate in frequency channels that are not currently occupied by users in allocated radiofrequency services. Methodologies are developed to determine feasible operating frequencies, elevation angle, and azimuth angle for OTHR operation using the ray-tracing technique [3]. Ray-tracing is a way of determining the path of radio waves through a system with regions of varying propagation properties. The process involves a step-by-step integration of differential equations that describe the propagation of these waves through dispersive and anisotropic media like the ionosphere. Unlike optical ray-tracing, in which the refractive index is typically constant for a given medium, ray-tracing through the ionosphere must account for the complexities of a spatially and temporally varying refractive index, where changes in the ionospheric electron density correspond to changes in the refractive index. Haselgrove described a method of using Hamilton's equations for geometrical optics to calculate the path of rays through the ionosphere [15]–[16].

Algorithms were developed to find all usable transmitter settings that are capable of sending a signal to any desired destination [3]. Typically, the destinations of OTHR signals are located anywhere between 1000 km and 3000 km away from the transmitter. There are three different transmitter settings that are taken into consideration: elevation angle, azimuth angle, and radar frequency. The elevation angle parameter of the transmitter is the initial angle that the transmitted radar beam makes with respect to the surface of the earth, while the azimuth angle is defined as the initial angle that the directional component of the beam that is parallel to the surface of the earth makes with due East. The azimuth angle is measured counter-clockwise from due East to the horizontal component of the radar beam. However, the information developed by these algorithms are complemented by information developed from another component of the overall OTHR project that researches what frequency bands at any given date and time DRDC is legally permitted to operate on. Together, these two sub-facets of the OTHR project managed by DRDC are responsible for developing means to determining appropriate transmitter settings for a desired target area of illumination.

Since the ray-tracing code reached an acceptable level of maturity, real-world testing for the OTHR Ionospheric Condition Monitoring System (ICMS) commenced its implementation. It was decided that the first test of applying OTHR would be to try and detect a Boeing 777-300 aircraft's routine commute to Beijing from the JFK airport in New York. To do this, input parameters for the OTHR transmitter had to be determined to be such that it would produce ground scatter that covered the section of the aircraft's flight path that ranges from a 1000 km to 3000 km ground distance away from the transmitter [3].

The approach to executing this task was to first attain information on the spatial and temporal nature of the flight path of the target aircraft by analyzing its historical flight data. The name of the flight the target aircraft regularly executes is flight JFK CA990. Records of its flight data were found on the website FlightAware. Flight data for this flight was acquired for the date of August 16, 2015. The website provided tables that displayed the position of the plane with respect to time, along with its cruising altitude at each position, etc. The flight path was observed at 15 minute intervals. The transmitter being used for this project has a frequency resolution of 50 kHz, with a frequency range from 3 MHz to 30 MHz. The step of 0.5 degrees was used for the elevation angle. The elevation versus frequency plots that correspond to the usable frequency bands for the illumination of parts of flight CA990 have been published in [3]. Update rates were provided every 15 minutes from 2:45 p.m. to 4:30 p.m. Usable radar frequencies were presented in Figure 22 [3] as a function of time for all elevation angles.

At 2:45 p.m., the flight is 1100 km away from the transmitter. The carrier frequencies that can be used in this case are given in the horizontal x-axis. Radar frequencies in the 3–21 MHz ranges can be selected for all rays landing within 150 km of the target located 1100 km away from the transmitter. The aircraft flies away from the transmitter as a function of time. At 3:30 p.m., the aircraft is 1900 km away from the transmitter. Radar frequencies in the 14–22 MHz range can be selected at this time. At 4:30 p.m., the aircraft is 3100 km away from the transmitter. Results suggest that the larger the ground range, the higher the radar frequency can be selected to detect the target [3]. For the purpose of merging, only the frequency range between 2 and 22 MHz is considered. The percentage of desired frequency channels over the available bandwidth were calculated as 43%, 26%, 21%, 17%, 20%, 17%, 15%, and 12% for times 2:45 p.m. to 4:30 p.m., in 15 minute intervals, respectively.

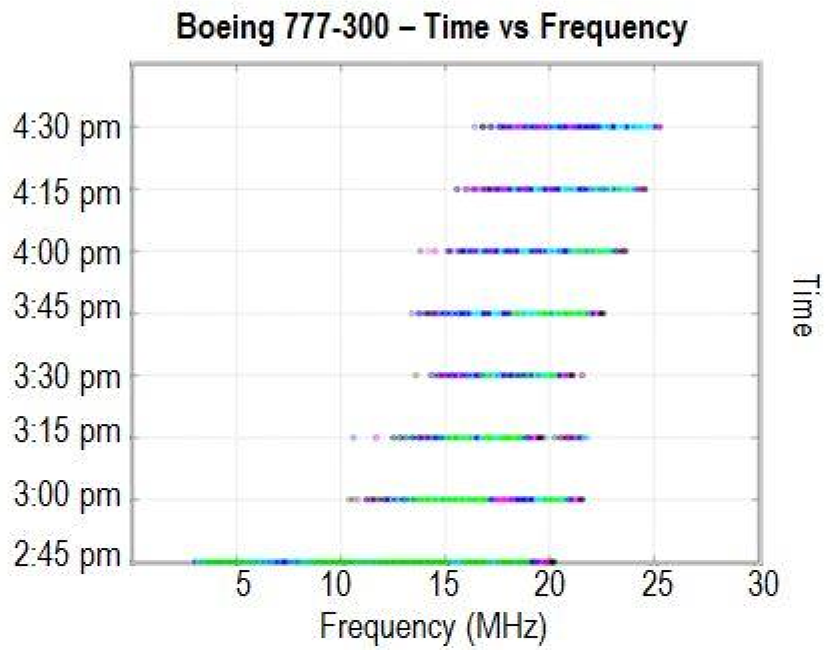

Figure 22: *Usable frequency bands as a function of time determined from ICMS for the illumination of flight CA990.Different colors correspond to different error tolerances: green—landed < 10 km from target, blue—landed 10–20 km from target, purple—landed 20–50 km from target, pink, landed 50–100 km from target, and black—landed 100-150 km from target [3].*

3 Merging of FMS and ICMS

The objective of this frequency monitoring exercise was to determine how many frequency channels are available for a particular mission and to verify that options remain available over the full mission. The output of the FMS is a list of frequency channels that have been identified as available for OTHR use. For this merging exercise, the minimum bandwidth required to determine a band of frequencies is unoccupied was set at 10 kHz. The output of the ICMS is a list of desired operational carrier frequencies for a particular mission. Both lists need to be merged in order to produce the final list of carrier frequencies that can be used to operate the OTHR transmitter. In this section, merging of the two systems is described and results are provided.

Each list is produced at different rates of time. At this time, the FMS has the ability to update each second but is updated each minute in order to save time computationally. This is because the code runs off-line with large set of data collected previously and processed afterwards. The ICMS is updated every 15 minutes. Once a list of desired operational carrier frequencies is received at a particular time for the mission, it is temporally aligned with the FMS list. This is currently done manually, as data collection time is currently not captured and both system outputs start at different times. For instance, the FMS started recording at 11:00 a.m. while the ICMS started recording at 2:45 p.m. FMS data for the first 3 hours and 45 minute are not required in this mission. An ICMS desirability vector is created where each desired carrier frequency provided by the ICMS at a particular time is assigned a desirability value of 1. All other frequency channel values over the desired bandwidth are assigned a desirability value of 0. The frequency resolution of each system differs. The frequency resolution of the FMS is 1.22 kHz while the frequency resolution of the ICMS is 50 kHz. In order to properly merge both sets of frequency channels, the size of the ICMS desirability vector needs to match that of the FMS availability vector. The size is increased by assigning place holders with a desirability value of 0 between desired carrier frequency values. For any mission, once the desired operational carrier frequency is known, it is important to verify that that particular frequency channel is available and unoccupied. The final list of desired and available carrier frequency channels is created by applying the Boolean AND operation to both FMS and ICMS vectors. See truth table in Table 1, where x represents the FMS availability vector and y represents the ICMS desirability vector. For each time period of the mission, the final list of desired and available carrier frequency channels was produced. Results are presented in Figure 23 to Figure 30 from 2:45 p.m. to 4:30 p.m., respectively.

Table 1: *Truth table for AND operation used in determining final SMS occupancy vector.*

x	y	x AND y
0	0	0
0	1	0
1	0	0
1	1	1

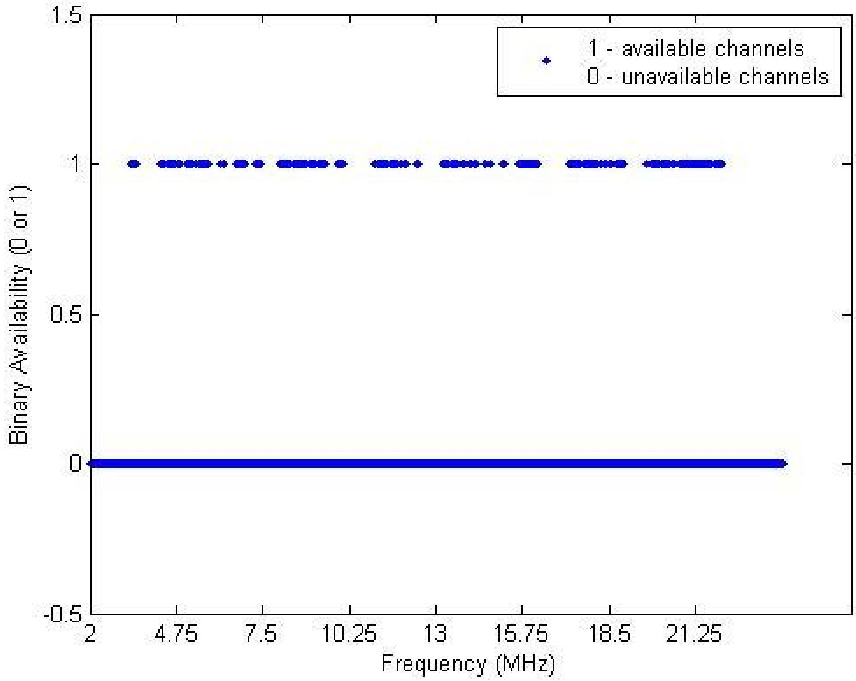

Figure 23: *Usable frequency bands determined from SMS for illumination of flight CA990 at 2:45 p.m.*

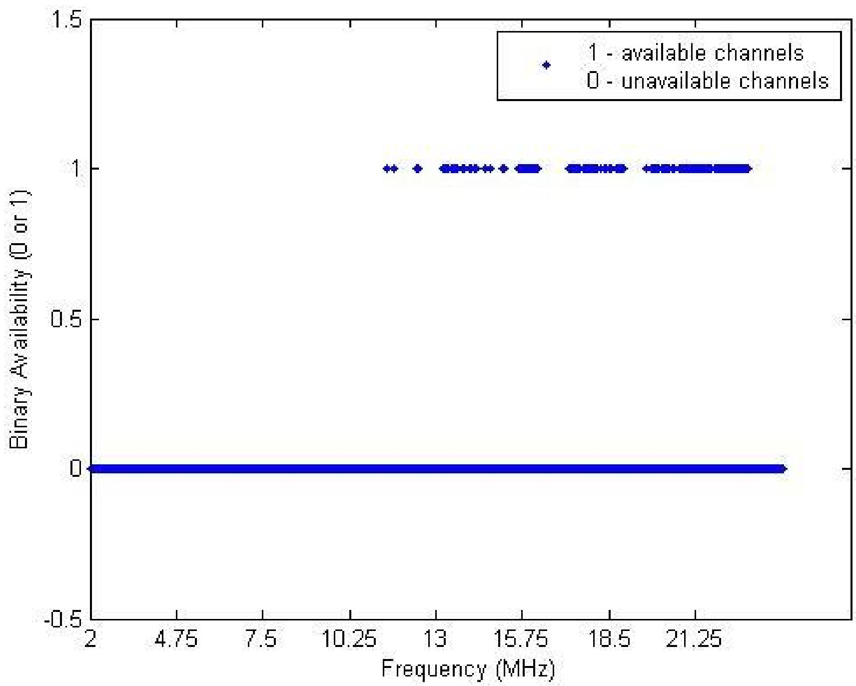

Figure 24: *Usable frequency bands determined from SMS for illumination of flight CA990 at 3:00 p.m.*

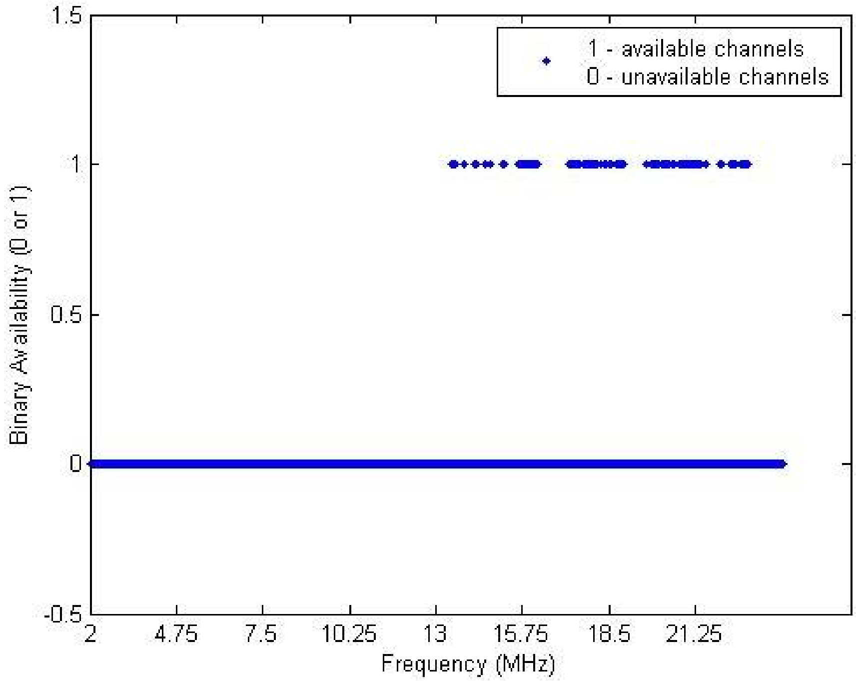

Figure 25: *Usable frequency bands determined from SMS for illumination of flight CA990 at 3:15 p.m.*

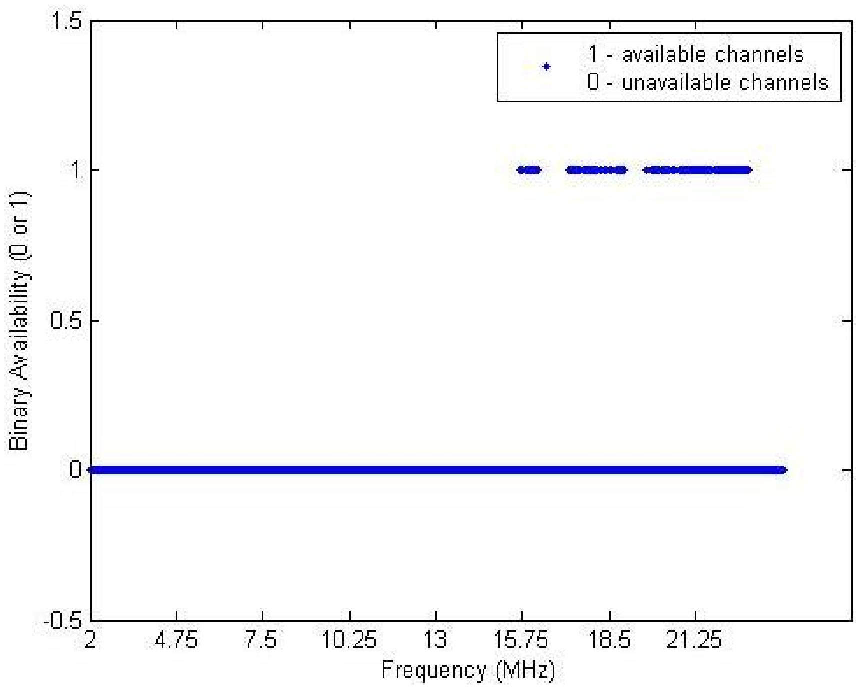

Figure 26: *Usable frequency bands determined from SMS for illumination of flight CA990 at 3:30 p.m.*

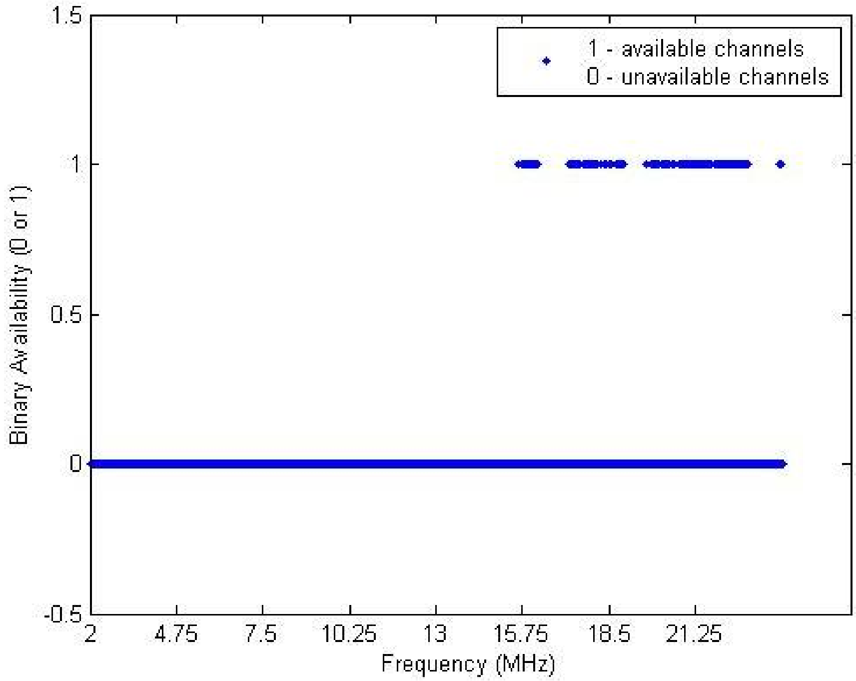

Figure 27: *Usable frequency bands determined from SMS for illumination of flight CA990 at 3:45 p.m.*

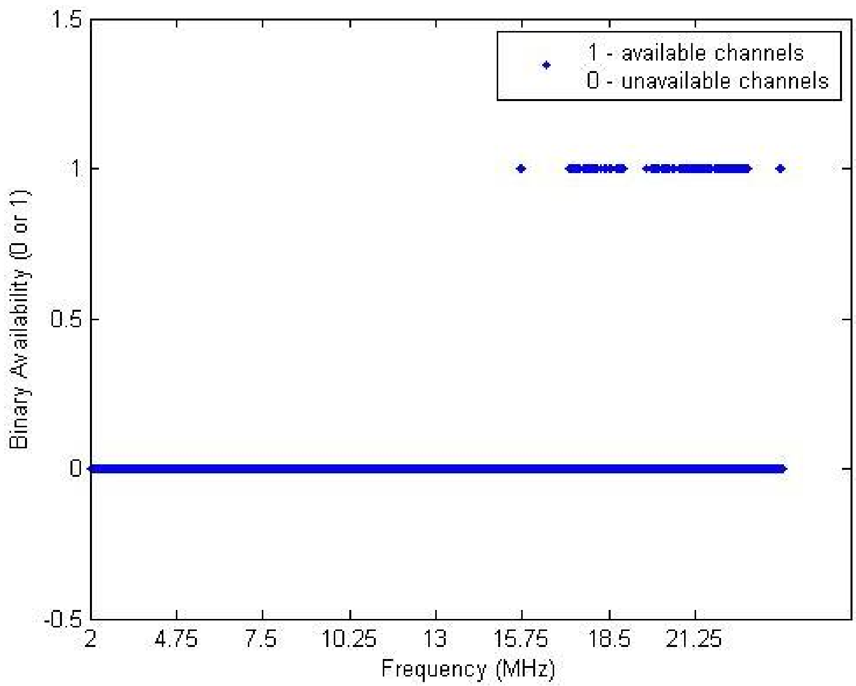

Figure 28: *Usable frequency bands determined from SMS for illumination of flight CA990 at 4:00 p.m.*

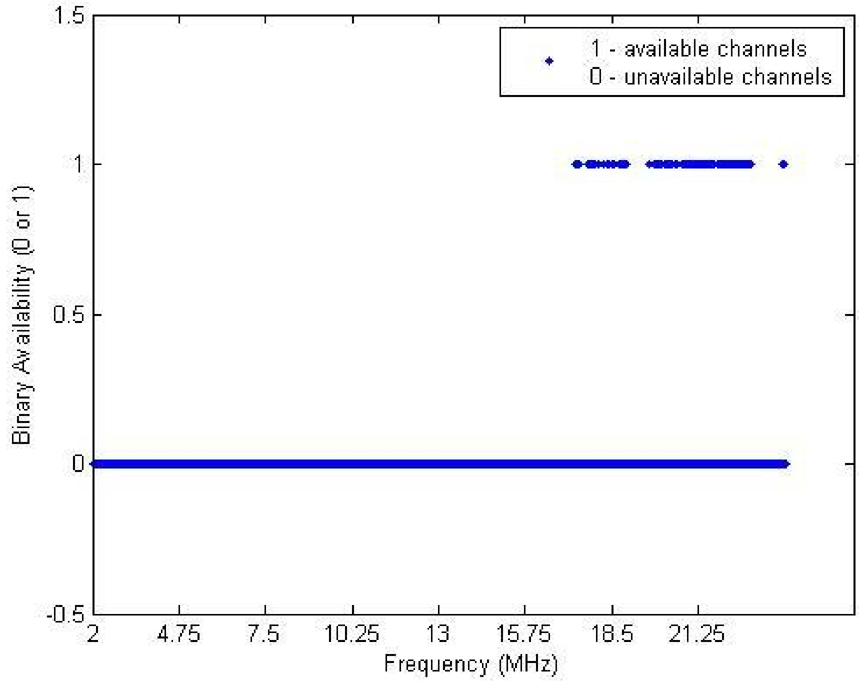

Figure 29: *Usable frequency bands determined from SMS for illumination of flight CA990 at 4:15 p.m.*

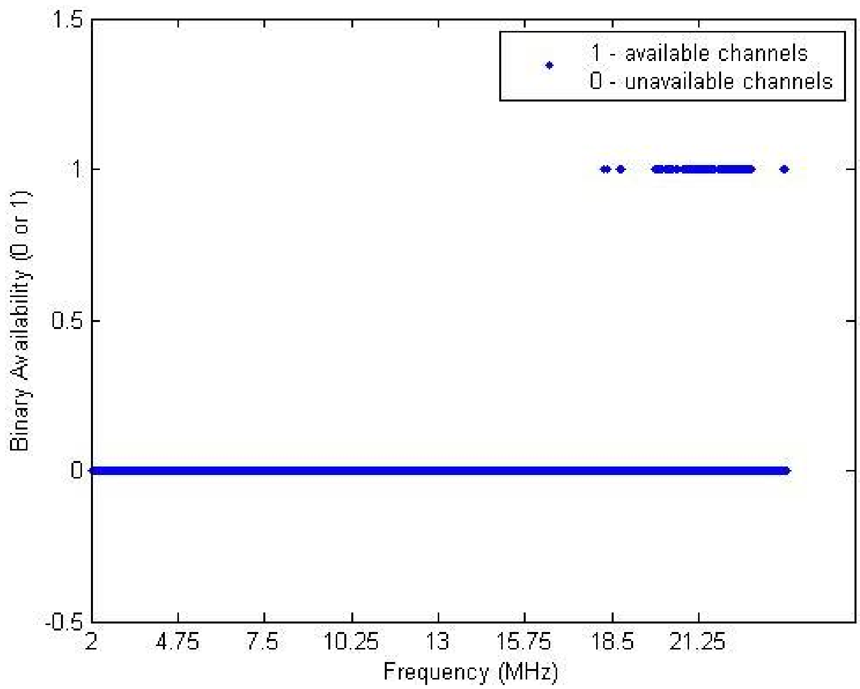

Figure 30: *Usable frequency bands determined from SMS for illumination of flight CA990 at 4:30 p.m.*

The merged results are also tabulated in Table 2. The percentage of available frequency channels after merging over the number of desired frequency channels from the ICMS varied from 51.01% to 63.79%. The SMS final list of available frequency channels vary from 58 to 176 channels. There appears to be ample choice for OTHR transmitter operation in this mission. The percentage of available frequency channels after merging the FMS and the ICMS over the entire spectrum varied from 0.35% to 1.07%. There is a way to increase the number of desired and available frequency channels after merging. This can be achieved by using a finer frequency resolution of the ICMS to include more desired frequency values. Though this is possible, it is more time consuming to process the ICMS and might not be necessary if a suitable transmit frequency value can be found over the period of the mission.

Table 2: *Merged FMS and ICMS results.*

Tracking Time (pm)	Number of desired frequency channels from ICMS	Number of desired and available frequency channels after merging	Percentage of available over desired frequency channels
2:45	345	176	51.01%
3:00	210	113	53.81%
3:15	164	87	53.05%
3:30	138	89	64.49%
3:45	161	92	57.14%
4:00	137	83	60.58%
4:15	116	74	63.79%
4:30	95	58	61.05%

A decision algorithm needs to be implemented in order to choose the final carrier frequency from the list received by the SMS. The decision should be based on the current and past occupancy data. Parameters that could be considered in the decision include the size of the available bandwidth, the amount of time a frequency channel has been continuously available, the amount of time a frequency channel has been available over a period of time, the history of frequency channel use, as well as the frequency separation between the preferred value and what is available.

4 Summary, Analysis, and Future Work

DRDC – Ottawa research Centre is developing an experimental OTHR with the potential for surveillance of the Canadian North. A SMS is a critical component of the OTHR, assessing the spectral environment and identifying portions of the HF band of operation available for the system to use. In this report, the merging of two important sub-systems of the SMS, namely the merging of the FMS and the ICMS, was presented using a simulated commercial aircraft tracking exercise as a mission. The exercise involved tracking the Air China Flight CA990 commercial aircraft from New York's JFK International Airport to Beijing's Capital Airport, flying over Canada.

The FMS provides a list of available frequency channels for use by the OTHR transmitter. For this mission, a list was created and updated over a 24 hour period at an update rate of one minute over a frequency range set between 2 MHz and 22 MHz with 1.22 kHz resolution. Availability was examined with the minimum bandwidth required to specify non-occupancy set at 10 kHz, 20 kHz, and 40 kHz. Results indicated availability decreased with increased minimum bandwidth, but even at 40 kHz bandwidth, there were always more than 20% available channels over the course of the 24 hour period, and 19.17% of the frequency channels were available 80% or more of the time. The ICMS provides a list of desired frequency channels to operate the OTHR transmitter. For this mission, a list was created and updated every 15 minutes from 2:45 p.m. to 4:30 p.m. over a frequency range of 2 MHz and 22 MHz with 50 kHz resolution. As the plane of this mission flew further away, the amount of desired frequency channels to track the plane decreased, from 43% of the entire frequency range at 2:45 p.m. to 12% of the entire frequency range at 4:30 p.m. The desired frequency channels also shifts from the lower end to the higher of the spectrum as the plane moves further away.

Merging of the FMS and ICMS to form the SMS involves temporal matching and vector formatting before applying the Boolean function AND. The two main objectives of this experiment were met. The number of frequency channels available for this particular mission was determined for each 15 minute update. It was verified that options remained available over the full mission. The percentage of available frequency channels after merging the FMS and the ICMS over the entire spectrum varied from 0.35% to 1.07%. The percentage of available frequency channels after merging over the number of desired frequency channels from the ICMS varied from 51.01% to 63.79%. This percentage can be increased by applying a finer frequency resolution of the ICMS output though may not be necessary. This exercise demonstrated that there is ample choice for OTHR transmitter operation for this mission.

The ultimate goal is to have a real-time functional SMS capable of continuously managing the OTHR transmitter. Future work will include the design of a real-time SMS with a decision algorithm to choose the operational carrier frequency as well as the implementation of a communication channel with the OTHR transmitter.

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List of Symbols/Abbreviations/Acronyms/Initialisms

DND	Department of National Defence
DRDC	Defence Research and Development Canada
DSTKIM	Director Science and Technology Knowledge and Information Management
FMS	Frequency Monitoring System
HF	High Frequency
ICMS	Ionospheric Condition Monitoring System
OTHR	Over-the-Horizon Radar
R&D	Research & Development
SMS	Spectrum Management System

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DRDC – Ottawa Research Centre is developing an experimental Over-the-horizon Radar (OTHR) with the potential for surveillance of the Canadian North. A Spectrum Management System (SMS) is a critical component of the OTHR, assessing the spectral environment and identifying portions of the High Frequency (HF) band of operation available for the system to use. In this report, the merging of two important sub-systems of the SMS, namely the merging of the Frequency Monitoring System (FMS) and the Ionospheric Condition Monitoring System (ICMS), was presented using a simulated commercial aircraft tracking exercise as a mission. The exercise involved tracking the Air China Flight CA990 commercial aircraft from New York's JFK International Airport to Beijing's Capital Airport, flying over Canada. Merging of the FMS and ICMS to form the SMS involves temporal matching and occupancy vector formatting before applying the Boolean function AND. The two main objectives of this experiment were met. The number of frequency channels available for this particular mission was determined for each 15 minute update. It was verified that options remained available over the full mission. The percentage of available frequency channels after merging the FMS and the ICMS over the entire spectrum varied from 0.35% to 1.07%. This mission exercise demonstrated that there is ample choice for OTHR transmitter operation and more options could be available by increasing ICMS frequency resolution. The ultimate goal is to have a real-time functional SMS capable of continuously managing the OTHR transmitter. Future work will include the design of a real-time SMS as well as the implementation of a communication channel with the OTHR transmitter.

RDDC Ottawa développe actuellement un radar transhorizon (OTHR) expérimental destiné à assurer éventuellement la surveillance du Nord canadien. Composante essentielle de l'OTHR, le système de gestion du spectre (SGS) évalue l'environnement spectral et y relève les portions de la bande des hautes fréquences (HF) qu'il peut exploiter. Le présent rapport fait état de la démonstration de la fusion de deux sous-systèmes importants du SGS, à savoir le système de surveillance des fréquences (SSF) et le système de surveillance des conditions ionosphériques (SSCI), dans le cadre d'un exercice simulant le suivi d'un aéronef commercial en tant que mission. L'exercice consistait à suivre l'itinéraire du vol CA990 d'Air China, de son point de départ, à l'aéroport international JFK de New York, à son point d'arrivée, à l'aéroport Capital de Beijing, en passant par l'espace aérien du Canada. La fusion du SSF et du SSCI pour constituer le SGS fait appel à l'appariement de données temporelles et le formatage de vecteurs d'occupation avant d'appliquer la fonction booléenne AND. Les deux grands objectifs de l'exercice ont été atteints. Le nombre de canaux de fréquences, disponibles pour les besoins de cette mission en particulier, a été déterminé à intervalles de 15 minutes. Il a été vérifié que des options demeurent disponibles tout au long de la mission. Le pourcentage de canaux de fréquences disponibles dans l'ensemble du spectre après la fusion du SSF et du SSCI variait de 0,35 à 1,07 %. Le présent exercice sous forme de mission a permis de démontrer qu'il existe amplement de canaux disponibles pour exploiter l'émetteur OTHR et que leur nombre pourrait être accru en augmentant la résolution en fréquence du SSCI. Le but ultime est de disposer d'un SGS en temps réel fonctionnel qui puisse gérer l'émetteur OTHR en continu. Les travaux à venir porteront sur la conception d'un SGS en temps réel et sur la mise en œuvre d'un canal de communication avec l'émetteur OTHR.

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Over-the-horizon radar; spectrum management system; frequency monitoring system; ionospheric condition monitoring system; merging