A Novel Approach of Semi-blind Frequency Selection for HF Regional Emergency Maneuver Communication

Dai-hui Mo[1,2](✉), Guo-jun Li[3], Xiao-fei Xu[3], Lu Tan[3], and Ya-kun Xing[3]

[1] Department of Electronic Engineering, Tsinghua University, Beijing, China
modh14@mails.tsinghua.edu.cn
[2] Academy of Military Sciences PLA China, Beijing, China
[3] HF Communications Engineering Lab of CQ, Chongqing Communication College, Chongqing, China

Abstract. Shortwave regional mobile communication relies on regional ionospheric vertical detector for frequency forecast. The inherent properties of full band, high power and fixed detection result in the difficulty of real-time deployment in complex terrains. In this case, from the perspective of communication fusion detection, with comprehensive utilization of broadband passive monitoring and low SNR detection technology, we propose a semi-blind frequency selection mechanism for regional mobile shortwave communication. First, we acquire the optimal scanning frequency in the working frequency band based on the full range of passive monitoring, which abandons the electromagnetic pollution made by the full band scanning. This mechanism can act as the basis for the use of existing narrow band shortwave radio bidirectional detection. Then, we get the active optimal frequency perception based on the portable shortwave radio and the optimal frequency selection. Finally, we work out the problem of low efficiency and poor concealment in the high-power independent detection, which is of great significance to the promotion of the regional emergency mobile shortwave communication in complex environments.

Keywords: Cognitive radio · Active detection system
Passive frequency selection · Real-time spectrum monitoring

1 Introduction

China has been suffering from frequent and various natural disasters such as earthquakes and floods, resulting in great economy loss and casualties. The emergency communication is an important guarantee for punctual, efficient, safe and reliable operations in all aspects of emergency management, such as preventing preparation, monitoring, early warning, disposal rescue, rehabilitation and reconstruction. The near vertical incidence skywave (NVIS), an important regional

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emergency communication mode, could cover 300 Km in complex terrains without blind spots or the terrains limits. In some areas like alpine canyon or jungle gully, since the satellite communication, VHF communication and other means alike are affected by the wave distance transmission, bad weather environment and many other factors, the unique characteristic of ultra-horizon transmission and mobile capabilities of shortwave NVIS communication becomes the only way of emergency mobile communication, which meets the high, middle and low altitude blindfold coverage of complex terrains reaching 300 Km.

The short wave communication [1] band ranges from 3 MHz to 30 MHz. The short wave NVIS sky wave is a propagation mode with a high elevation angle (near 90°) antenna, which needs to work below the critical layer of the ionosphere F_2 (f0F2), otherwise it will be penetrated by the ionosphere and the system could hardly work. The ionosphere f0F2 is directly related to the magnetic storm, absorption, solar activity, latitude, climate and so on, and changes dynamically with seasons, months and days. Therefore, in order to adapt to the time-varying dispersion characteristics of NVIS channel, shortwave NVIS communication must work out the dynamic selection problem of communication frequency. The reliability, timeliness and maneuverability of frequency selection have been the bottlenecks in the development of shortwave NVIS mobile communication.

However, long-term short-wave frequency detection system and communication system [2–4] are different from each other, whether it is an active detection method or a passive detection method, different signal waveform, transceiver and antenna equipment should be used in the communication system. On one hand, that leads to the poor applicability and feasibility of the communication frequency predicted by the detection system in the existing communication system. In addition, the active detection method has also been haunted by problems such as high power, poor mobility and electromagnetic environment pollution. On the other hand, passive detection method also has the problem of low reliability and blind coverage of the link. Based on the combination of active detection and passive detection, this paper proposes a new portable low-power semi-blind selection method suitable for shortwave NVIS sky-wave maneuvered communication. Based on real-time estimation of broadband spectrum and passive monitoring Ionospheric critical frequency, the critical frequency is used as a priori knowledge to design a narrow-band ionospheric detection window. A new low-power mobile short-wave channel detection technique suitable for existing shortwave communication equipment is proposed, which detects the narrow-band window channel characteristics in real time, and select the current optimal frequency for communication.

2 The Current Situation of Frequency Selection in Shortwave NVIS Communication

For a long time, the frequency planning of shortwave NVIS communication [5–7] has been mainly adopting the ionospheric vertical detector to obtain the critical frequency, realizing the shortwave communication frequency forecast on the basis of this frequency. The ionospheric vertical detector emits the radio pulses as the frequency changes with time, receiving the ionospheric reflection signals of these pulses at the same location, measuring the transmission delay of the radio and the round trip, and obtains the relationship between the reflection height and the frequency called Ionospheric high frequency chart. The ionospheric characteristic parameters of each layer such as the critical frequency and minimum frequency of E, F_1, F_2 and Es layers are obtained. The distribution of electron density with height can also be obtained by frequency conversion.

China Institute of Radio Propagation is the main development organization of the ionospheric vertical detector, which deployed 19 fixed detection sites in the territory, continuously detecting in the entire shortwave band (3–30 MHz) for 24 h. Detected sites transmission power is usually greater than 400 W, and some even up to 1000 W to obtain a reliable ionospheric critical frequency and other parameters. After obtaining the current ionospheric critical frequency, the available frequency forecasts are usually given at equal intervals within the range of 2 MHz below the critical frequency. Since the detection system and the communication system are independent from each other, the predicted frequency obtained by this equal interval division has not been subjected to the actual ionospheric channel test, and the availability of the prediction frequency is insufficient.

In addition, because the existing detecting sites are mostly built in the more developed large and middle-sized cities, the performance of ionospheric detection and forecasting is poor in remote areas. In order to meet the needs of the construction of emergency shortwave communication in remote mountainous areas, in recent years, many organizations such as the Institute of Radio Propagation have developed the vehicle-mounted short-wave ionospheric vertical detection equipment. However, the transmission power of this equipment is mostly above 400 W. In case of limiting energy supply in complex terrain environments such as remote mountainous areas, the application of such active detection equipment is severely limited.

Due to this situation, the Institute of Radio Propagation has recently further developed a passive and source-free detection equipment, which is used to detect ionospheric frequencies in complex terrains. The main idea of passive detections is that dozens of detecting sites are built as a beacon station, and portable ionospheric detection equipment only needs to receive the signals sent by beacon stations. The ionospheric propagation characteristic parameters away from the beacon station could be obtained by the interpolation fit. It can be seen that this passive detection method puts aside the launch part of the equipment, with the result that volume power consumption is greatly reduced, while mobility and concealment are greatly enhanced. However, the frequency of NVIS estimation, which is estimated by numerical fitting, is limited by the accuracy of the algorithm itself, and the performance of the area where the beacon information is difficult to cover (land border, ocean island reef) is obviously degraded.

In conclusion, the existing short-wave NVIS frequency detection and prediction methods [8,9] suffer from large power consumption and poor mobility (difficult to expand in complex terrains) in active detection modes, or low precision and poor practicability (cannot meet the need of remote NVIS frequency forecast) in passive detection modes.

3 Semi-blind Selection Methods for HF NVIS Communication

In this paper, an information processing terminal is added to the existing shortwave communication system to realize the integration of probing communication, which avoids the additional radiation interference caused by the independent detection system, reduces the system costs and enhances the applicability of the frequency selection. Because the frequency detection system has wider scanning bandwidth and higher peak power than the shortwave communication system, it is necessary to work out the problem of narrowband and low power frequency detection by frequency detection and forecasting based on the communication system. Therefore, this paper presents a short-wave NVIS semi-blind frequency detection method, using narrowband and low power to achieve short-wave NVIS communication frequency selection, which includes two steps: obtaining a priori scanning frequency based on broadband spectrum monitoring, and activating sensing channel characteristics based on low power bidirectional detection.

3.1 Obtain a Priori Scanning Frequency Based on Broadband Spectrum Monitoring

As the national short-wave detection station is conducted by Institute of Radio Propagation and the launch signal waveform is not open to public, other organizations cannot develop the ionospheric passive detection system. This paper uses the local short-wave signal in whole spectrum band to calculate the frequency of the energy center of the ionospheric reflection signal in local areas, which is called reflection center frequency [10] (RCF) in this paper and is based on the short-wave broadband spectrum monitoring. RCF directly reflects the best frequency of the current ionospheric NVIS propagation, and can determine the best frequency band for the current work. However, the shortwave communication is also closely related to channel interference noise, and the ionosphere has a dynamic time-varying characteristic in the short term. To achieve reliable communication, it is necessary to analyze and capture the spectrum holes in the best working frequency band for obtaining the priori scanning frequency and achieving the frequency optimization through selecting to resting channel.

With the progress of software radio technology [11], the current shortwave communication field has developed a practical full-band software receiver to record the entire shortwave 30 MHz band in real-time, hence it provides a possibility for real-time calculation of short-wave NVIS reflection center frequencies. For the widely used $G31DDC$ broadband shortwave receiver, the A/D sampler digitally processes the signal directly at the RF end with a sampling frequency of 100 MHz. According to the Nyquist sampling theorem, the A/D sampler can achieve the real-time monitoring to the occupancy situation of full- frequency band (up to 50 MHz), which in the realization is also absolutely feasible. In order to obtain a more detailed spectrum in a band occupancy situation, the sampled signals could be digitally down-converted and further processed by the IF digital signal filtering process, which helps get 20 KHz–2 MHz different bandwidth range of detailed spectrum after getting windowed and FFT processed once again. When the observation window bandwidth is 20 KHz, the maximum resolution could get up to 1 Hz.

After a large number of experiments, we have demonstrated that the frequency of the ionospheric reflection center RCF (some documents call it the interference center frequency) obtained by the short-wave full-band monitoring can effectively characterize the short-wave NVIS propagation characteristics, and it seems that the available frequency of the current period has good operability and high predicted accuracy [12]. The implementation method is as follows:

(1) Use the broadband receiver to scan the full range of shortwave, and record the interference energy value at each scanning frequency point;
(2) According to the $CCIR258-2$ report, the relationship between the median and the frequency of the anthropogenic noise figure is provided [13]. The interference energy value is corrected to minimize the effect of artifacts, since the noise is not ionized Layer reflection, if included in the calculation of RCF, will cause a greater deviation;
(3) Set the threshold based on the MUF and LUF provided by the ITS propagation model, and eliminate the effects of sudden interference and strong signal interference at the adjacent station;
(4) Calculate the reflection center frequency (RCF) value using the following formula:

$$ICF = \frac{\sum_{i=1}^{n} F_i \times D(F_i)}{\sum_{i=1}^{N} D(F_i)}$$

where F_i is the i-th frequency, $D(F_i)$ is the spectral energy value of F_i.
(5) Make$(RCF - 1.5, RCF + 1.5)$the best working window for NVIS
(6) Frequency monitoring modules rapidly output the quiet frequency point within$(RCF-1.5, RCF+1.5)$ as a priori scanning frequency setting. Figure 1 shows the ICF measured data of the Chongqing area obtained by this method, which has a high degree of coincidence with the measured communication frequency of the Chongqing area. Through the line test of Chongqing - Beijing, Chongqing - Wuhan and other places, it is shown that the optimal frequency obtained by this method could improve the communication capability obviously when applied to the special route.

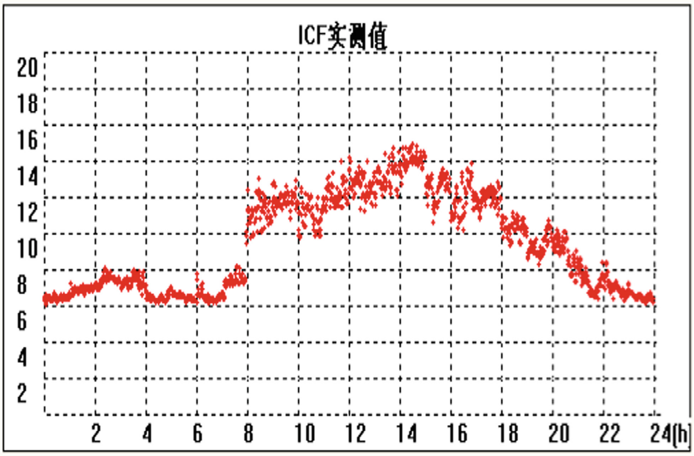

Fig. 1. ICF based on broadband spectrum monitoring.

3.2 Active Sensing Channel Characteristics Based on Low Power Bidirectional Detection

In order to utilize the existing portable shortwave communication equipment for spectrum sensing to obtain the actual propagation characteristics (including bidirectional SNR, frequency offset, delay spread, etc.) of the above mentioned NVIS channel, it is necessary to make the system operate in narrowband channel and low power mode. In this paper, adaptive multi-carrier differential frequency shift keying (ADMFSK) is used as the detection waveform, conducting forward error correction through RS code. The low signal-to-noise ratio (−20 db) and the harsh working conditions of the strong multipath interference (8 ms) are exchanged at lower symbol rate in exchange for low-power NVIS communication.

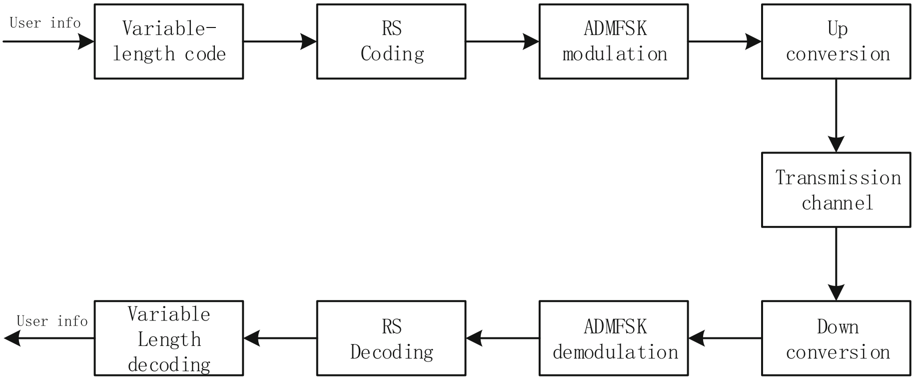

Fig. 2. Schematic diagram of frequency detection waveform structure.

This multi-carrier serial differential technology is particularly suitable for helicopters, unmanned aerial vehicles and other high mobility targets. The concrete implementation is shown in Fig. 2.

Due to the low signal-to-noise ratio of the application environment and the fast fading of the mobile NVIS channel, the synchronous carrier (as shown by f_0 in Fig. 3) is specifically set for ADMFSK modulation.

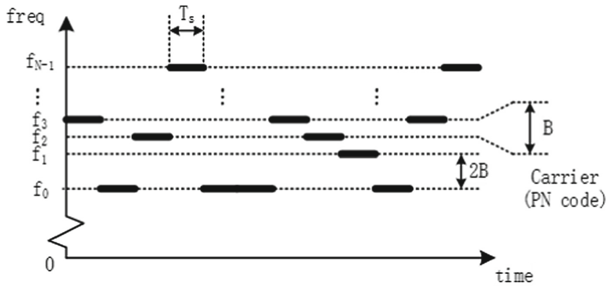

Fig. 3. Schematic diagram of ADMFSK modulation scheme.

On one hand, the carrier sends the preset PN code repeatedly by keying, and then performs the detection of the auto correlation peak through the receiving port to realize the group synchronization of the data. On the other hand, the received carrier frequency is used as the reference of other carriers frequency, thereby reducing the transmission frequency of the overall frequency error. The black and bold line in Fig. 3 indicates that there is a tone signal transmission over the corresponding frequency band of the time period, assuming that there are N frequency points for the transmission of the signal, where the smallest frequency point f_0 is used to transmit the carrier and synchronization signal, f_1–f_{N-1} is used to transmit data, it is worth noticing that only the data on the carrier wave is 0, that can transmit data on f_1–f_{N-1}, although the design sacrifices the transmission rate, the inter-carrier interference is avoided at the same time, while the use of a separate frequency of the fundamental and synchronous PN code transmission can ensure the synchronization of the signal access on maximum priority. In addition, it can also transmit a different preset PN code to achieve a certain degree of the information encryption, while the use of PN code autocorrelation characteristics, it can use a simple autocorrelation peak to achieve rapid access and use short-term good channel environment or interference gap to operate payload transmission.

The detection waveform has a single frequency at any time and the signal phase is continuous and the amplitude remains constant, which is to say that in the entire transmission process peak-to-average ratio is kept at a relatively constant state and can improve the efficiency of transmitted signal as much as possible while ensuring that the waveform is not distorted (extended), that have a significant practical significance for the single-soldier, bicycle and other mobile users whose power and antenna efficiency are limited in bad environments.

3.3 HF NVIS Communication Semi-blind Selection Frequency System Program

On one hand, the semi-blind selection system in this paper mainly includes a portable computer terminal, broadband receiver and portable shortwave radio, and the system structure is shown in Fig. 4, which actively detect the frequency selection completely relying on the existing short-wave radio transceiver to the antenna, and baseband signal modulation and demodulation completely in the form of software. On the other hand, as the existing shortwave radio has no broadband receiver function, to configure a miniature shortwave broadband receiver through the USB port access to computer terminals, it is necessary to achieve a priori scanning frequency calculation.

Due to the fact that the portable radio's transmit power is 20 dB less than the ionospheric vertical detector transmitter, the detecting waveforms, used by semi-blind selection method, can reliably work in the background of −20 dB noise. In addition, due to the strong multi-path delay existing in the NVIS propagation, the long symbol width, which means low-speed communication, is exchanged

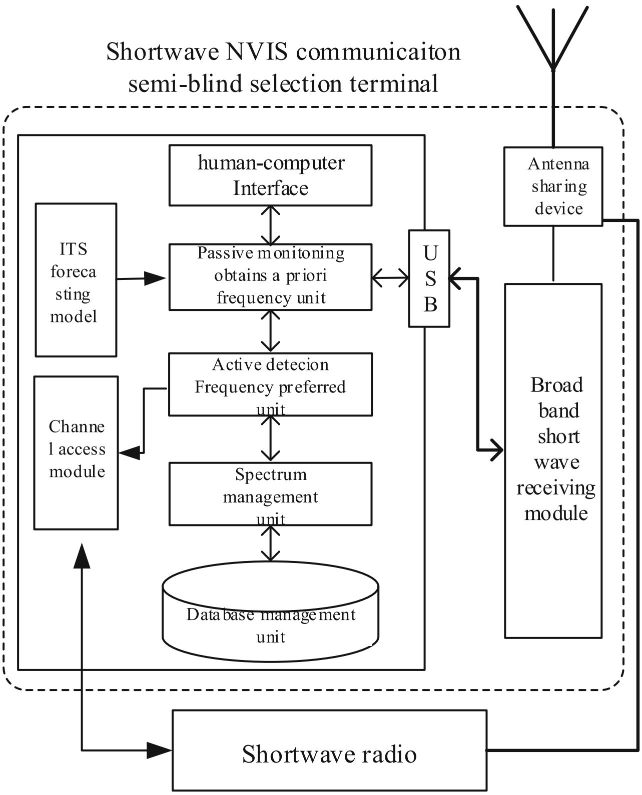

Fig. 4. Block diagram of short-wave NVIS communication semi-blind selection system.

for the low signal-to-noise ratio in this paper. Meanwhile, the radio channel conversion time, antenna tuning time, radio continuous transmission capacity and other factors taken into account and referring to that ionospheric vertical detector's scanning cycle usually is half an hour, the semi-blind selection method proposed in this paper actively senses to the 30 transcendental frequency of 3 MHz best working frequency band in 1 h, which means every 2 min a channel of two-way detection is completed. When 24 h of continuous detection is completed, 30 channels are obtained at each time period, and a total of 720 channels are actually transmitted.

Although the channel sensing and passive monitoring of the two modules share a pair of antennas, the hardware channel devices are independent from each other, which provide the probability for channel sensing and passive selection frequency working at the same time [14]. So the central station can use the radio station for a priori frequency active detection, and at the same time, it can also achieve a priori frequency-set real-time calculation by optimizing the timing design, the system can achieve a long term and uninterrupted exploration, as long as the prior scanning frequency informed to mobile users in real time through other means (such as Beidou SMS), and the system timing is shown in Fig. 5.

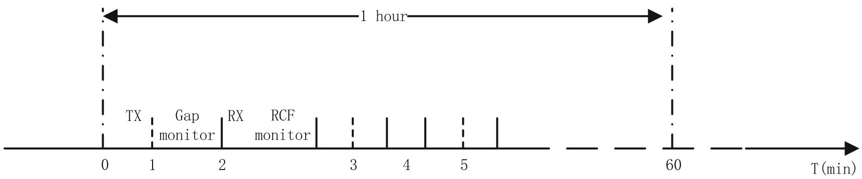

Fig. 5. Semi-blind selection system timing chart.

4 Summary

With the rapid development of cognitive radio technology, the idea of dynamic frequency optimization and distribution in the field of shortwave communication has been widely discussed and recognized. Based on the idea of cognitive software radio and the analysis of combing the main problems of current shortwave NVIS communication frequency selection, this paper proposes a portable shortwave NVIS communication semi-blind selection taking advantage of wide-band passive monitoring technology and low SNR detection technology, the composition of the system structure, waveform characteristics, working process, timing and others alike are described in detail. This semi-blind selection method, which utilizes broadband passive monitoring and radio active cognition, will be more suitable for maneuver detection of ionosphere in complex terrain environments by the deep fusion of detecting communication, and at the same time, it is helpful to avoid the problem of low communication efficiency caused by independent frequency selection system and have great significance to enhance the emergency mobile communication capability of shortwave areas in complex terrain environments.

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