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A Proposed RFI Intelligent Monitoring and Positioning System of FAST

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Abstract

As the most sensitive single-dish radio telescope, it is a great challenge for the Five-hundred-meter Aperture Spherical radio Telescope (FAST) to mitigate Radio Frequency Interference (RFI). The solutions for RFI mitigation of FAST consist of the Electromagnetic Compatibility (EMC) design and measures of the instruments, the maintenance of a Radio Quiet Zone (RQZ) and post-processing RFI removal algorithms. However, with the development around the FAST site, the radio environment has been affected and become complicated. In order to strengthen the operation and management of the FAST RQZ, a RFI intelligent monitoring and positioning system has been proposed, which focuses on monitoring, identifying , and positioning RFI sources, especially some mobile interference sources such as drones in the core zone of the RQZ with the radius of 5 km around the FAST site. The preliminary design and two key technologies including RFI intelligent identification and RFI source localization have been discussed roughly.

1 Introduction

Due to its extreme sensitivity and the observing frequency coverage from 70 MHz to 3 GHz, Radio Frequency Interference (RFI) mitigation has been one of the most significant steps to protect the observations of the Five-hundred-meter Aperture Spherical radio Telescope (FAST) from RFIs [1]. With the establishment and operation of the FAST RQZ since 2013 (Figure 1), the radio environment around the FAST site has maintained a relatively quiet and stable state [2]. Especially in the core zone with the radius of 5 km of the FAST site, it is strictly forbidden to set up and use radio stations, or construct facilities with electromagnetic radiation.

Nevertheless, with the development around the FAST site, there are more and more potential RFIs that will affect the radio environment. In order to ensure the long-term, safe, and effective operation of the FAST, a long-term intelligent monitoring and positioning system around the FAST site is required to decrease the impact caused by surrounding RFI sources, particularly the mobile interference caused by drones, vehicle stations et al.

2 Preliminary Design

The preliminary design of this system consists of at least one central station located in the FAST site and three remote stations distributed in the core zone of the FAST RQZ. The RFI measurement data of stations will be transmitted by optical fibers to the data center in the FAST site. A RFI database and associated software packages will be developed to identify and locate RFI sources. The main technical specification of the system includes that the receiver sensitivity should be better than 90 dBm, the working frequency band should cover the FAST observation bands, and the monitoring angle range should be 360° azimuth for each monitoring station.

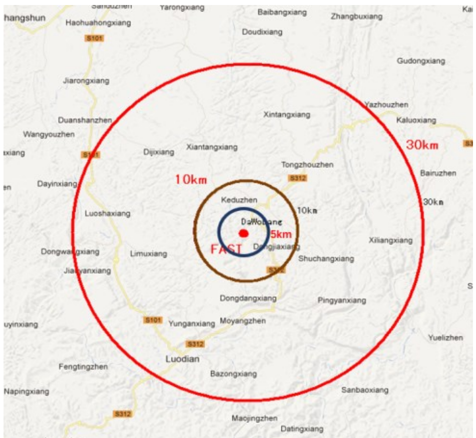

Figure 1. Distribution of FAST RQZ: the core zone with the radius of 5 km, the middle zone with the radius between 5 and 10 km, and the remote zone with the radius between 10 and 30 km.

Currently, two key techniques of this system need to be developed. One is RFI intelligent recognition, and the other is RFI source location. In the following sections, the initial ideas about these techniques will be discussed briefly.

2.1 RFI Intelligent Identification

As mentioned above, on the one hand, the system should have the ability to continually monitor the radio environment around the FAST site. On the other hand, the system also needs to scan in real-time to detect and recognize RFIs automatically caused by wireless communications, illegal radio services and other mobile devices, etc. Due to the complexity and large volume of the RFI data, the study on RFI intelligent identification technique is required.

In order to realize the intelligent identification of RFI, first of all, it is necessary to establish a RFI database based on historical monitoring data whose category is already known [3]. Meanwhile, the characteristics like center frequency, bandwidth, level, modulation, and symbol rate can be extracted, and the parameters can be estimated [4]. Under the above conditions, the RFI category models can be established through training of machine learning algorithms like Support Vector Machines (SVM) or K-Nearest Neighbor (KNN) et al. [5]. During RFI monitoring stage, firstly, the abnormal signals that exceed the threshold can be automatically and quickly found by setting the threshold for comparison. After that, the characteristics and parameters of the abnormal signals can be calculated and used as the input to the RFI category classifier derived by machine learning to obtain the category to which the RFI belongs to. Figure 2 shows the flow chart of the RFI intelligent identification system.

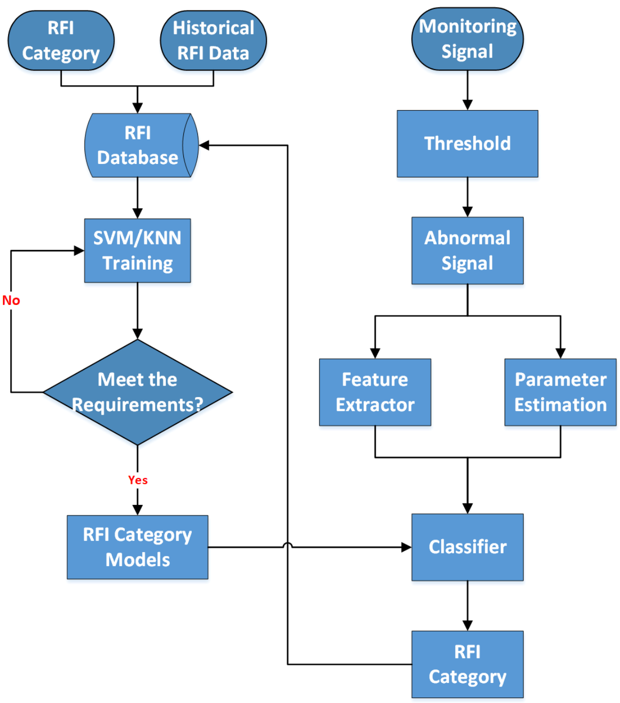

Figure 2. Flow chart of the RFI intelligent identification system.

2.2 RFI Source Localization

In order to meet the requirements of electromagnetic environmental protection around the FAST site, it is necessary to locate the source of RFI with high precision, and immediately provide accurate location information. Currently, the Direction Finding Cross positioning, the Time Difference of Arrival (TDOA) positioning and the Doppler Frequency Difference positioning are main radiation source positioning techniques. Among them, the TDOA has the advantages with high positioning accuracy, convenient networking and simple equipment, which is suitable for our situation.

Generally speaking, the TDOA uses the time difference between different monitoring stations to locate the signal source. Figure 3 shows the schematic illustration of the TDOA. Firstly, the remote stations transmit the same signal data measured at the same time to the central station. Equation 1 and 2 show the received signals from two remote stations.

$$x_1(t) = s(t) + n_1(t) \tag{1}$$

$$x_2(t) = A * s(t-\tau) + n_2(t) \tag{2}$$

Where $x_1(t)$ and $x_2(t)$ are the received signals from two remote stations, $s(t)$ and $A * s(t-\tau)$ are the same RFI signal received from two remote stations separately, τ is the time difference of arrival between the two stations, $n_1(t)$ and $n_2(t)$ are the noise of the two stations separately. Then, the time difference of arrival between remote stations can be derived by cross-correlation algorithm described as:

$$\begin{aligned} R_{x_1x_2}(\Delta t) &= A * R_{ss}(\Delta t - \tau) \\ &+ A * R_{sn_1}(\Delta t - \tau) + R_{sn_2}(\Delta t) + R_{n_1n_2}(\Delta t) \end{aligned} \tag{3}$$

Where $R_{x_1x_2}$ is the cross-correlation between $x_1(t)$ and $x_2(t)$, R_{ss} is the autocorrelation of the $s(t)$, R_{sn} is the cross-correlation between the RFI and noise signals. Hypothetically, the RFI and the noise signals in different stations are uncorrelated. Then, Equation 3 can be simplified to:

$$R_{x_1x_2}(\Delta t) = A * R_{ss}(\Delta t - \tau) \tag{4}$$

When $\Delta t = \tau$, the value of $R_{ss}(\Delta t - \tau)$ is the largest, which also means that $R_{x_1x_2}(\Delta t)$ is the largest. Therefore, the time difference τ can be obtained by finding the maximum value of $R_{x_1x_2}(\Delta t)$. Then the time difference can be converted into the distance difference, and the hyperbolic curve of RFI source distribution can be obtained. Finally, the position of the RFI source can be derived from the intersection point between multiple curves.

In fact, for a radiation source in three dimensions, at least three stations are required to locate the RFI source. Three stations can form three single-sided hyperboloids, the three hyperboloids intersect two curves, and the two curves intersect at a point. Typically, the time measurement error is 109 ns for radio signals with a bandwidth greater than 10 KHz, and the corresponding distance measurement error is about 30 m [6].

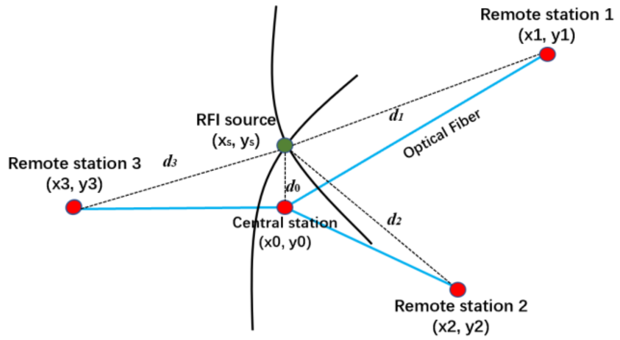

Figure 3. Schematic illustration of TDOA algorithm.

3 Conclusion and Prospective

The maintenance of RQZ has contributed to protect the radio environment around the FAST site effectively. Nevertheless, with the rapid development of local society, the RFI intelligent monitoring and positioning system is required to ensure the long-term, safe, and effective operation of FAST. The preliminary studies on the techniques to realize high precise positioning of RFI sources in motion and meet the required accuracy of the RFI category models have been carried out. Meanwhile, the research on the related techniques are also ongoing.

In the next two years, a prototype of this system will be established and tested practically. With this system, we can not only support the maintenance of FAST RQZ, but also ensure scientific outputs of FAST.

4 Acknowledgements

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5 References

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