

Interference Sensing based on Wireless Sensors Synchronized with Optical Fiber Link

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Abstract: We proposed and demonstrated interference sensing method to accurately measure the location of interference source. The wireless sensors are synchronized with optical links for high resolution time difference of arrival measurement. © 2024 The Author(s)

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1. Introduction

In dynamic spectrum situations, efficient interference tracking is of the highest priority. This is because the demand for robust spectral resource management is always growing. Nevertheless, existing methods encounter substantial obstacles when it comes to functioning autonomously. Low Earth orbit satellites produce interference that impacts radio telescope arrays, necessitating the sharing of tracking data for these satellites with the radio telescope arrays. This dependence on pre-existing information is not consistent with the ultimate objective of autonomous functioning in interference sensing [1,2]. When the sources of interference and the signals of interest (SOI) use different systems, it often becomes difficult to precisely identify and separate the two. This disparity exposes a significant shortcoming in standard methods of tracking interference.

A time difference of arrival-based object tracking system provides an alternative to traditional GPS system in that it does not require satellites to actively send signals to the target for location triangulation [3]. This avoids causing more interference by not releasing signals towards the interference source. It is especially important in situations where the use of specific frequencies is regulated, such as observatories with arrays of radio telescopes, as any additional interference is unwanted. The passive sensing system employs a network of sensors that passively receive signals emitted by the interference sources themselves. This method enables precise identification of the source of interference without requiring the sensors to actively transmit signals. As a result, it preserves the integrity of the interference sensing and prevents additional disturbances. Furthermore, by incorporating Radio-over-Fiber (RoF) technology, our system enhances signal transmission range with minimal attenuation, which is essential for increasing the transmission range of signals without the usual attenuation associated with radio-frequency (RF) communication. Our system attempts to counter these difficulties through employing optical fibers for the transmission of radio frequencies, providing notable benefits such as little signal attenuation and large data transfer capabilities [4]. This enables a more distinct and dependable signal over extended distances compared to what classic RF technologies can accomplish.

In this paper, we proposed and demonstrated an optical fiber linked passive sensing model. By combining RoF technology, our system is able to collect signals from interference sources without actively transmitting any signals. This integration improves the accuracy of detection while also minimizing the possibility of further interference. This system improves detection accuracy while preserving the integrity of spectrum-controlled environments, ensuring minimal interference and optimal functionality.

2. Principle and System Setup

Fig. 1. (b) and (c) shows the principle of traditional GPS and passive sensing model. Traditional GPS measures the distance between a satellite and a target by sending signals to the target (Fig. 1. (b)). In order to locate the source of interference, the act of transmitting measurement signals from the sensors to the interference source creates unwanted extra interference. This will be problematic in situations where spectrum control is necessary. Fig. 1. (a) shows the system setup of our proposed fiber-linked passive sensing model. Upon receiving an RF signal, the antenna modulates it onto an optical fiber for long-distance transmission. Subsequently, the optical signal is converted back into an electrical signal by a photodiode (PD) and fed into a processor for computation. This processor is connected to numerous sensors, ensuring synchronization of the received signals, thereby facilitating the calculation of positional information. In this system, sensors passively detect signals from the interference source at predetermined times recording different arrival timings. These times enable the computation of the temporal disparities between the arrival of signals at various sensors. By mapping the source onto a hyperbola (Fig. 1. (c)) whose focuses are the coordinates of the sensors. The source's location can then be determined using these differences. The point of intersection between many hyperbolas generated by independent pairs of sensors then can determine the exact position of the source. The coordinate of the interference source (x, y) is determined by the hyperbola curve:

$$2A = (t_1 - t_2) \times c = (t_{m2} - t_{m1}) \times c \quad (1)$$

In formula 1, t_1 and t_2 are time of signal transmit from the interference source to sensor 1 and 2. t_{m1} and t_{m2} are the measured arrival time of signal from sensor 1 and 2. c is the speed of light. The distance between the two sensors L can be measured and are defined as $L = 2C$. Then the arrival time difference ($t_1 - t_2$) defines the distance between two vertices for the hyperbola, see formula 2:

$$\frac{x^2}{A^2} - \frac{y^2}{B^2} = 1, \text{ where } B^2 = C^2 - A^2 \quad (2)$$

Subsequently, we can employ numerous sensors to obtain multiple hyperbola curves. The source of interference is the intersection of those hyperbolic curves (Fig. 1. (c)).

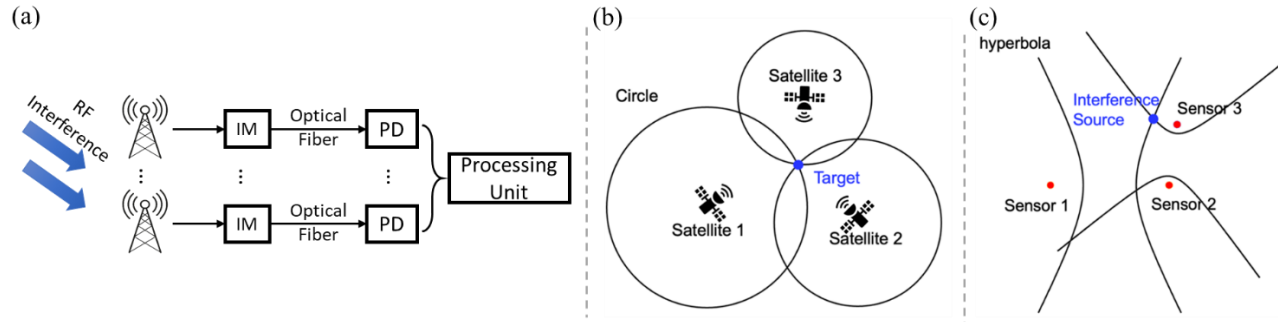


Fig. 1. (a) Proposed passive sensing system based on optical fiber link. IM: Intensity Modulator. PD: Photodetector. (b) Traditional GPS system principle. (c) Passive sensing system principle.

3. Results and Analysis

The results are shown in Fig. 2. We are utilizing a total of four antennas, with three of them serving as sensors and one as a transmitter. The sent signal is a modulated pulse signal with carrier frequency of 863 MHz. The hyperbola curves calculated are shown in Fig. 2. (a). The locations of sensors are marked as red and the actual interference location is marked as blue. Fig. 2. (b) provides a zoom in view of Fig. 2. (a). The difference of measured interference location and the actual one is in centimeter scale.

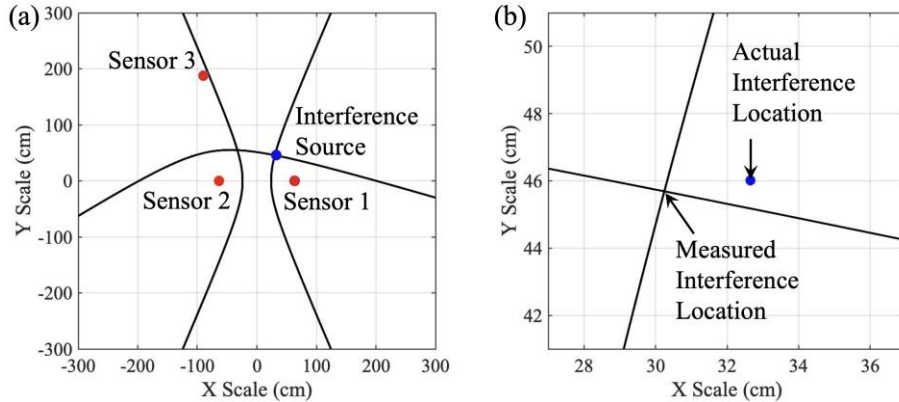


Fig. 2. (a) Experimental measurement of the interference source location. (b) provides a zoom in view of (a).

4. Conclusion

We proposed and experimentally demonstrated a passive sensing model based on Radio-over-Fiber technology, offering a robust solution for interference location tracking which does not require satellites to actively send signals to target. Through combining with radio over fiber technology, our system is able to function effectively during long-distance scenarios and achieve centimeter-level precision. This work is supported by NSF grant number ECCS-2128608.

References

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