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TDOA Location Accuracy Experiment

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Abstract. TDOA-based wireless signal location technology has been extensively used in engineering applications. Due to the lack of quantitative TDOA location accuracy index benchmark, there is the absence of reference basis in the development of TDOA application system indicators and performance evaluation. In this paper, the engineering radio frequency receiver network is used to form the TDOA location system. Under the condition of non-multipath, TOA time is used to simulate TODA to monitor the signal of the location target radio frequency signal source, and the relationship between the location accuracy of TDOA and the signal bandwidth is evaluated. The experimental results can be used as a benchmark for performance evaluation of TDOA location system.

1. Introduction

With the rapid development of electronic technology, wireless location systems have been extensively used in civil and military fields. TDOA (Time Difference of Arrival) wireless location technology uses three or more test base stations to measure the time difference between the arrival of the same signal and each station; for example, in the case of three base stations, three hyperbolic curves are obtained, and the intersection point is the source [1]. TDOA technology is applied to systems such as radio monitoring, mobile communication network location services and cellular system optimization design because of its high precision, easy network implementation, and ability to deal with broadband low spectral density signals [2]. However, at present, there is a lack of TDOA location precision quantitative index both at home and abroad, which makes users more blind in customizing TDOA application system index and performance evaluation, resulting in the formulation and evaluation of quantitative index too strict or too wide, which brings great difficulties to the application and development of TDOA technology. To this end, this paper will provide a benchmark for evaluating the performance of TDOA location systems through a large number of experiments.

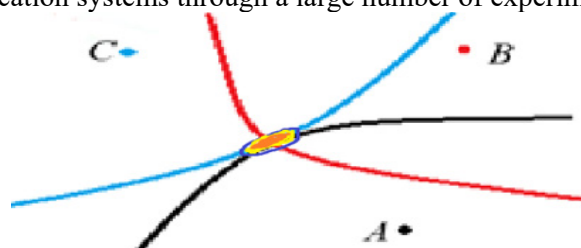


Fig.1 TDOA location schematic



2. Factors Affecting the Location Accuracy of TDOA

(1) Bandwidth: According to the Fourier transform, the narrower the frequency domain bandwidth of the signal, the wider the time domain, the wider the correlation function, the correlation peak will be weakened[3], and the difficulty of peak detection will increase, thus affecting the accuracy of time delay estimation.

(2) Modulation type: Different modulation types has different demodulation methods, and the accuracy of information demodulator for different demodulation methods is also different, resulting in different location accuracy[4].

(3) Sampling rate: Generally, the higher the sampling rate, the better the location accuracy, but if the sampling rate is too high, the receiver will be unable to process.

(4) Accuracy of location triangle area: Take three monitoring stations as an example, the deployment mode is generally centered on the source location, and the monitoring station is the vertex to form the triangle. When deployed in a positive triangle, the accuracy is the highest, but in the real environment, it is subject to the limitation of various factors is difficult to form a positive triangle.

(5) Carrier-to-noise ratio and noise: Excessive noise may cause the effective signal to be covered up, making it difficult to extract the effective signal.

(6) GPS location accuracy: TDOA location technology requires strict time synchronization mechanism among monitoring stations, and GPS location accuracy has a significant impact on time synchronization.

(7) Time-scale accuracy: When the data processing center processes the signal data, the delay of transmission and processing between each processing modules will increase the time difference among the monitoring stations, resulting in incomplete synchronization between the signal data.

(8) Multipath: In the real environment, due to the occlusion of buildings and the reflection of radio waves, there is a multipath effect, which will cause mutual interference between the peaks of correlation functions, affecting accuracy; The time-varying multipath is difficult to simulate reasonably in the experimental environment, so the experiment in this paper is mainly done without multipath or weak multipath.

3. Experimental Environment and Related Algorithms

3.1. Experimental environment

The experimental network of this paper is mainly composed of signal generator, B210 receivers, GPS timing systems, power systems, GIS module, 4G network module and data processing center, among which B210 receivers, GPS timing systems (using 1PPS pulse) and power systems constitute three same small monitoring stations. The experimental network structure of TDOA location technology is shown in Fig.2.

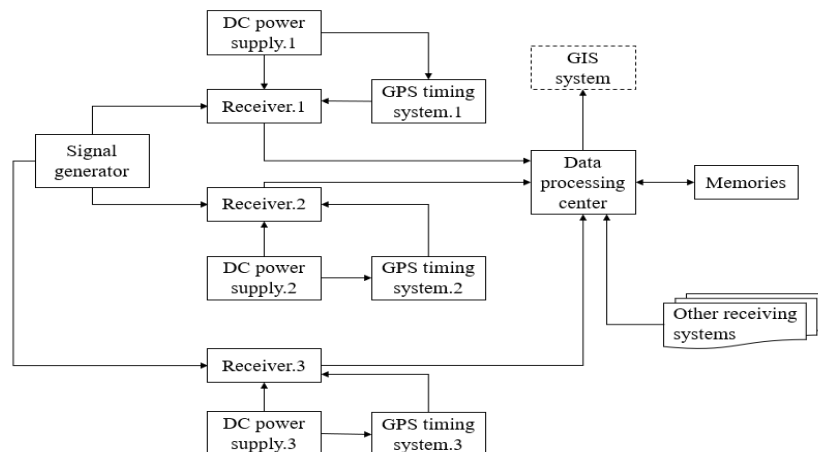


Fig.2 The experimental network structure of TDOA location technology

In the course of the experiment, the signal generated by the real signal generator is used as the information source to reasonably arrange the stations on the GIS module, and uses TOA(Time of Arrival) data to simulate the formation of TDOA data for different delays of each monitoring station. In addition to no multipath, other noise, time difference, frequency offset and other effects are the same as the real environment. The picture of the simulated small monitoring station is shown in Fig.3.



Fig.3 The simulated small monitoring station

3.2. Related algorithms of TDOA location technology

(1) Time difference estimation algorithm

In TDOA wireless locating method, domestic and foreign scholars have proposed many classic time difference estimation algorithm, such as the generalized weighted correlation time difference estimation algorithm[5], the algorithm preprocesses the signal at the front end of the receiver, enhances the frequency component of the signal with high signal-to-noise ratio, and suppresses the noise, thereby improving the reliability of the time difference estimation, and according to the different transmission channel, have different weighted function[6]; Among them, the generalized cross-correlation-phase transformation method (GCC-PHAT) has a certain anti-noise and anti-multipath ability[7], which is more widely used in the actual situation. The block diagram of GCC-PHAT principle is shown in Fig.4.

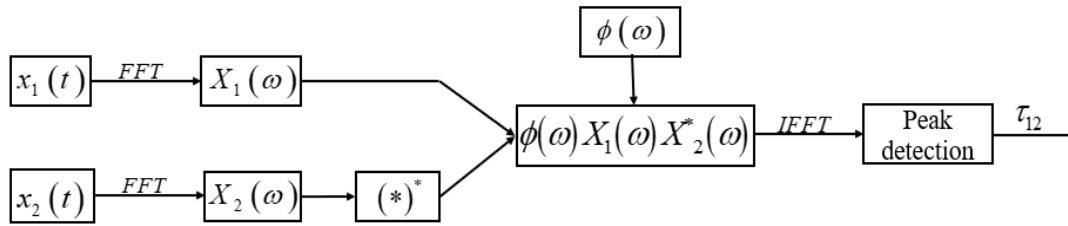


Fig.4 The block diagram of GCC-PHAT principle

Taking two monitoring stations as an example, the signals collected by the source through noise and other different propagation paths are obtained x_1 and x_2 , then getting $X_1(\omega)$ and $X_2(\omega)$ by fast Fourier transform, multiplying the complex conjugate $X_2^*(\omega)$ of $X_2(\omega)$ with $X_1(\omega)$ to obtain cross-power spectrum information, multiplying the obtained cross-power spectrum data by the frequency domain weighting function $\phi(\omega)$, and then inverse Fourier transform to obtain the delay estimate τ_{12} from the peak detection (The weighting function of PHAT is

$$\phi(\omega) = \frac{1}{|G_{x_1 x_2}(\omega)|} = \frac{1}{|X_1(\omega) X_2^*(\omega)|}.$$

(2) Time difference location algorithm

In the wireless location system, the distance difference from the source to each monitoring station can be obtained from the estimated value of TDOA, and multiple TDOA estimates can form a set of hyperbolic equations about the source position (if locating in three-dimensional space, we get a set of hyperbolic equations)[8]. When solving the hyperbolic equations, due to its nonlinearity, multi-value phenomena will appear during the location process, making the location result in "fuzzy"[9]. In order to avoid the problem of fuzzy solutions, this paper uses the following location algorithm:

In the experiment of this paper, the TDOA location system consists of three monitoring stations. The monitoring station is where the data processing center located is called the main station. The position of the monitoring station is (m_k, n_k) , and $k=0$ means the main station, $k=1, 2$ indicates two secondary stations. The position of the source is (p, q) , l_k represents the distance between the target and the k -th station, and Δl_k represents the distance difference between the target to the main station and the target to the k -substation, expressed as an equation:

$$\begin{cases} l_0^2 = (p - m_0)^2 + (q - n_0)^2 \\ l_k^2 = (p - m_k)^2 + (q - n_k)^2 \\ \Delta l_k = l_k - l_0 \end{cases} \quad (3-1)$$

Obtained by formula (3-1):

$$(m_0 - m_k)p + (n_0 - n_k)q = h_k + l_0 \cdot \Delta l_k \quad (3-2)$$

$$\text{among them } h_k = \frac{1}{2} [\Delta l_k^2 + (m_0^2 + n_0^2) - (m_k^2 + n_k^2)], \quad k = 1, 2.$$

The matrix form of equation (3-2) is:

$$WZ = G \quad (3-3)$$

$$\text{among them } W = \begin{bmatrix} m_0 - m_1 & n_0 - n_1 \\ m_0 - m_2 & n_0 - n_2 \end{bmatrix}, Z = \begin{bmatrix} p \\ q \end{bmatrix}, G = \begin{bmatrix} h_1 + l_0 \cdot \Delta l_1 \\ h_2 + l_0 \cdot \Delta l_2 \end{bmatrix}.$$

When the three stations are not in a straight line, W is reversible and can be obtained:

$$Z = W^{-1}G \quad (3-4)$$

$$\text{making } W^{-1} = [w_{kj}]_{2 \times 2}, \text{ from equation (3-4) can be obtained } \begin{cases} p = w_{11}(h_1 + l_0 \cdot \Delta l_1) + w_{12}(h_2 + l_0 \cdot \Delta l_2) \\ q = w_{21}(h_1 + l_0 \cdot \Delta l_1) + w_{22}(h_2 + l_0 \cdot \Delta l_2) \end{cases}.$$

$$\text{Making } \begin{cases} x_k = w_{k1}h_1 + w_{k2}h_2 \\ y_k = w_{k1}\Delta l_1 + w_{k2}\Delta l_2 \end{cases} \cdot k = 1, 2;$$

$$\text{then there is } \begin{cases} p = x_1 + y_1 \cdot l_0 \\ y = x_2 + y_2 \cdot l_0 \end{cases} \quad (3-5)$$

Substituting equation (3-5) into the first equation in equation (3-1) yields:

$$a \cdot l_0^2 + 2b \cdot l_0 + c = 0 \quad (3-6)$$

$$\text{among them } \begin{cases} a = y_1^2 + y_2^2 - 1 \\ b = (x_1 - m_0)y_1 + (x_2 - n_0)y_2 \\ c = (x_1 - m_0)^2 + (x_2 - n_0)^2 \end{cases}.$$

According to the above formula, the target position

where the source is located can be solved.

4. Analysis of experimental results

4.1. Analysis of correlation functions of different signal bandwidths

The signal bandwidth is a two-tuple function consisting of the signal symbol transmission rate and the modulation type, that is, $\text{signal bandwidth} = f(\text{symbol transmission rate}, \text{modulation type})$; the value of the signal bandwidth is smaller than the symbol transmission rate, and is positively correlated with the symbol transmission rate; the bandwidth of the signals of different modulation types is also different. As showed in Figure 5, the correlation function changes when different bandwidth signals are tested under different modulation types. Fig.5(a) shows the correlation function of the signal of different symbol transmission rate under MSK modulation. The width of the correlation function is inversely proportional to the signal bandwidth, and the peak position shows a certain offset. Fig.5(b) shows the different codes under QPSK modulation. The change in the correlation function of the rate signal is the same as that of Fig.5(a). The sharper the correlation function, the clearer the peak value; but as can be seen from the Fig.5, the signal bandwidth is not as wide as possible. The wider the bandwidth, the more frequency components are included. Different frequencies may have different delays on the transmission path. Causes the waveform of the correlation function to get distorted.

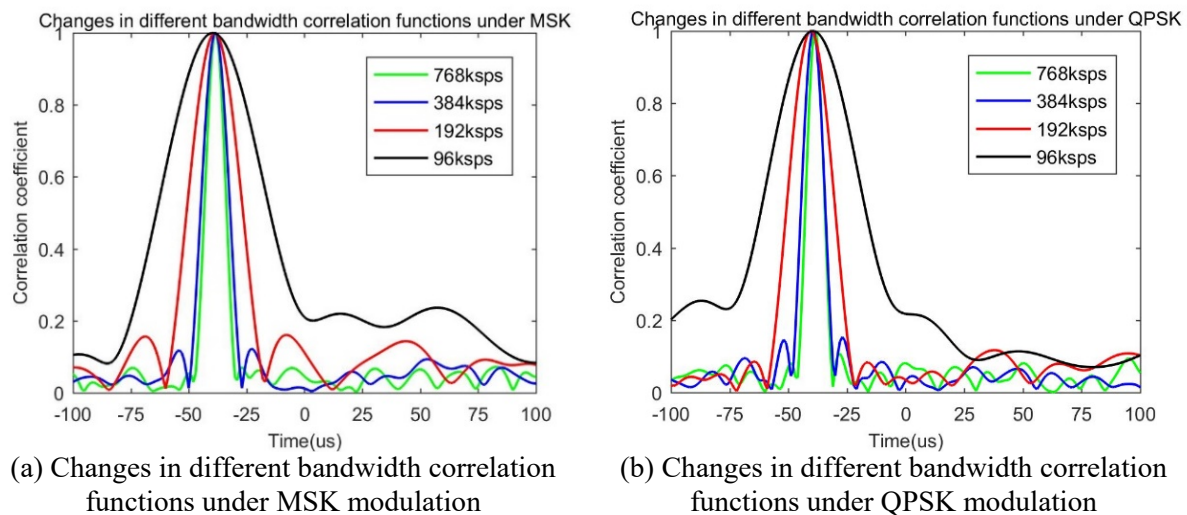
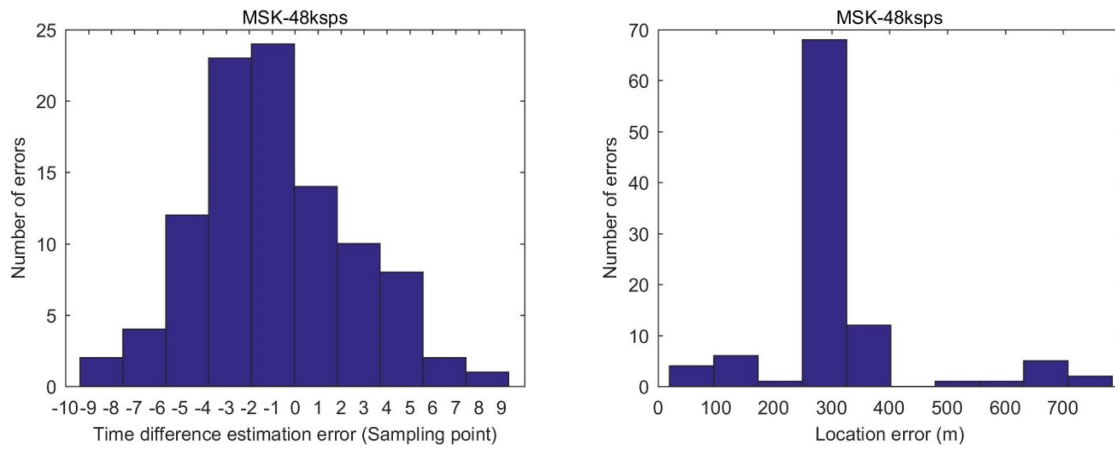


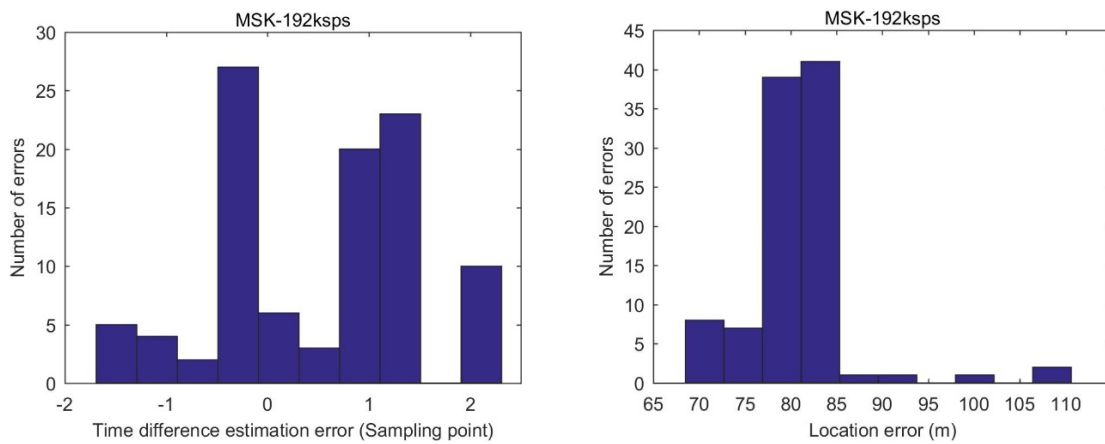
Fig.5 Variations of different bandwidth correlation functions under different modulated signals

4.2. Analysis of TDOA location accuracy under different signal bandwidths

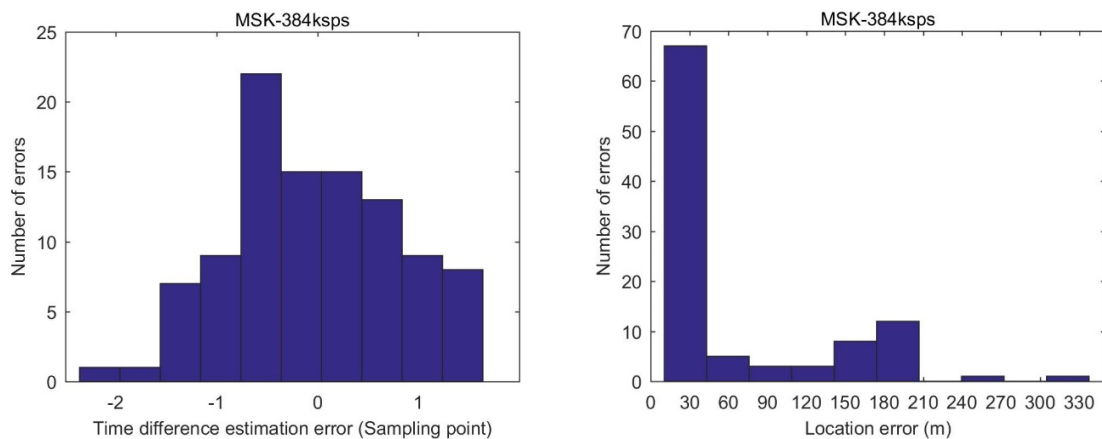
As showed in Fig.6, taking the MSK modulated signal as an example, sampling rate is 1.6MSPS, TDE(Time Difference Estimation) error and the location error are analyzed at 48kps, 192kps and 384kps symbol transmission rates, respectively. Under MSK modulation, the signal bandwidth of 48kps symbol transmission rate is about 30kHz, and the TDE error is large, which concentrated 1 to 9 μs , even up to 10; and the corresponding location error is concentrated 300 to 400m, even up to 700m. The signal bandwidth of 192kps symbol transmission rate is about 160kHz, and the TDE error is mostly concentrated below 1.5 μs and about 2 μs ; and the corresponding location error is mostly concentrated 70 to 85m and about 100m. The signal bandwidth 384kps symbol transmission rate is about 350kHz, and the TDE error is mostly concentrated below 1.5 μs ; the corresponding location error is mostly concentrated 30 to 60m and 150 to 210m.



(a) Histogram of TDE error and location error of MSK modulation signal with a symbol transmission rate of 48kps



(b) Histogram of TDE error and location error of MSK modulation signal with a symbol transmission rate of 192kps



(c) Histogram of TDE error and location error of MSK modulation signal with a symbol transmission rate of 384kps

Fig.6 Histogram of TDE error and location error of MSK modulated signals with different symbol transmission rates

5. Conclusion

In this paper, the TDOA location system is constructed by using the engineering RF receiver network, in the case of non-multipath, GCC - PHAT for time difference estimation algorithms and the TOA

simulation TODA to monitor the signal of the target RF signal source. After a lot of experiments, analyzing the relevant indicators that TDOA location accuracy can achieve under different signal bandwidths, the experimental results can be used as the benchmark for TDOA location system performance evaluation, and provide guidance for the performance of TDOA application system.

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