Wireless Emitter Location Estimation Based on Linear and Nonlinear Algorithms using TDOA Technique

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Abstract— Low-power devices such as cell phones, and wireless routers are commonly used to control Improvised Explosive Devices (IEDs) and as the communication nodes for the sake of command and control. Quickly locating the source of these signals is ambitious, specifically in a metropolitan environment where buildings and towers may cause intervention. This presents a geolocation system that compounds the attributes of several proven geolocation and error mitigation methods to locate an emitter of interest in an urban environment. The proposed geolocation system uses a Time Difference of Arrival (TDOA) approach to estimate the position of the emitter of interest. Using multiple sensors at known locations, TDOA estimates are achieved by the cross-correlation of the signal received at all the sensors. A Weighted Least Squares (WLS) solution, Linear least Square (LLS) method and maximum likelihood (ML) estimation is used to estimate the emitter's location. If the variance of this location estimate is too high, a sensor is detected and identified as possessing a Non-Line of Sight (NLOS) path from the emitter. This poorly located sensor is then removed from the geolocation system and a new position estimate is computed with the remaining sensor TDOA information. The performance of the TDOA system is determined through modeling and simulations. Test results confirm the feasibility of identifying a NLOS sensor, thereby improving the geolocation system's accurateness in a metropolitan environment.

Keywords*- Linear least squares, Maximum likelihood, Non line of sight, Non-Linear least squares, Time difference of arrival, Weighted linear least squares*

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I. INTRODUCTION

Geolocating the radio frequency emitters is one of the elemental capabilities of spectrum situational awareness and provides a variety of uses in military communications when working in tactical environments. Having knowledge on the position and power levels of a radio frequency emitter yields advantageous information situational awareness in DSA radio technology. The entire perspective is that of designing a hierarchical spectrum sensing architecture. The low-level communication nodes are used to sense the radio spectrum and provides the significant data while the intermediate level node, which is also known as the correlation engine, is responsible for accepting the reports from low-level nodes and offers spectrum situation alertness. This clustering of functionality eventually lowers the data overhead as sensing reports do not need to travel all the way up a network hierarchy before being processed and reported back down. The majority of the processing take place at the intermediate level in small sensor clusters. Low-power emitters are the extreme contributors to the complexity of the electronic warfare problems. They are generally used to control IEDs, often detonating the IEDs distantly without any warning. A variety of emitters can also be employed by terrorists for command and control devices. Instantly locating the source of the detonation signal is complex, mainly in a metropolitan environment where tall buildings and other signals can cause disruption. This research provides a geolocation system which uses the time difference of arrival (TDOA) technique to detect the emitters of interest in an urban environment.

Signals of interest, inclusive of the signals from air crafts and radars, are tracked down with receivers positioned and controlled by operators at a safe distance. Now, emitters of interest include key fobs, cordless telephones, mobile phones, wireless routers, and walkie-talkies. Collectively these devices operate through a broad range of the radio frequency spectrum. The divergence of these emitters presents a notable force protection challenge because at present only a little is known about how to locate them. The urban environment come out with increased challenges, which includes multi-path, signal scattering, and widespread interfering signals. At certain instants of time it is not possible to detect emitters, particularly from the safe stand-off distance that most geolocation systems presently use. The modern systems should possess the ability of reaching much closer distances of the emitter in order to detect its signal, while preserving the military controller safe from getting ruined. This means it is possible to deploy a geolocation system on an unmanned aerial vehicle (UAV) or unmanned ground vehicle (UGV). Installing the geolocation system onto a UAV enhances the size and mass restrictions to the already complex problem. These challenges highlight some of the many aspects that this difficult problem presents..

II. CATEGORIZATION OF LOCALIZATION

Localization schemes determine the position of an object or person with respect to another known location or within a coordinate system. During the last few years, several techniques have been proposed to provide an accurate estimation of the location of an unknown sensor node. Localization algorithms can be divided mainly into two categories.

1. Range-Based positioning.
2. Range-Free positioning

III. PROPOSED METHOD FOR LOCATING EMITTERS:

3.1 Time Difference Of Arrival (TDOA):

The TDOA-based approach to locating emitters is one of the most commonly used position location techniques. TDOA is used in many geolocation, operational and scientific applications and is widely used in sonar and radar to and the navigation (LORAN) and Decca, use the TDOA between a radio signal and position of a signal of interest. Many navigation systems, including long range multiple stations to determine a desired navigation position. The TDOA technique make use of the differences in the time that a signal appears at multiple receivers. Each TDOA measurement results in generating a hyperbolic curve which yields a set of possible positions. The equation of this hyperbolic curves is given by

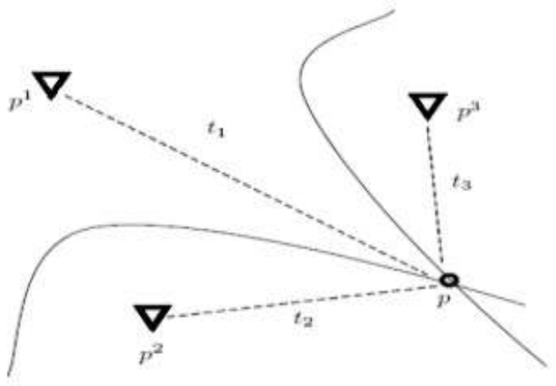

Figure 1. TDOA hyperbolic curves

$$R_{ij} = \sqrt{(X_i - x)^2 + (Y_i - y)^2 + (Z_i - z)^2} - \sqrt{(X_j - x)^2 + (Y_j - y)^2 + (Z_j - z)^2}$$

where the three-dimensional points (Xi; Yi;Zi) and (Xj ; Yj ;Zj) denotes the pair of receivers, i and j . A two-dimensional emitter's location can be predicted from the convergence of two or more hyperbolas originated from three or more TDOA measurements. An emitter's three-dimensional location estimate needs no less than four TDOA measurements to estimate its location.The hyperbolas in Figure 1 are composed of possible solutions generated from the time differences, Δt = ti - t1. From the intersection of the hyperbolas, the location of the emitter, p is estimated. Locating an emitter using the TDOA method is possible even if multi path is present. This method's ability to carry away multi path is a considerable advantage over the previous methods, particularly in locating emitters in urban environments where tall buildings and towers might cause notable reflections. To obtain a successful TDOA technique, there should exist at least one LOS path between the emitter and each receiver. If there exists a LOS path from the emitter to a sensor, and multi path is present, the signal with the least time delay is the LOS signal. The condition when there is no LOS path between the transmitter and a receiver. Another advantage in using TDOA over other methods is that using TDOA it is possible to locate unknown emitters passively and there is no need to synchronize the emitter's time with the receivers. While working with the TDOA technique for locating the source of a signal, it is not needed to know the time at which the signal left the emitter, and only the receiver's synchronization in time is needed. A timing reference that is commonly employed is global positioning system (GPS), but in metropolitan environments, gaining access to GPS satellites is repeatedly blocked by tall buildings or towers. One common approach that is used in time synchronization is by using atomic clocks, like Rubidium or Caesium time source. The ability to locate a signal using TDOA without any need of emitter's time synchronization is specifically important in passive detection of the signals. In passive detection, the attributes of the signal coming from the emitter are clearly unknown, so there is no way to obtain the exact time when the signal left the emitter. Estimating the unknown emitter's position rely upon the ability of measuring time differences of the signal as it arrives at various receivers.

3.2 Algorithms for source localization:

There are two types of estimators that can be used to solve the nonlinear equations that have been presented so far, equations. They are

1. Nonlinear approaches
   a. Maximum likelihood
   b. Nonlinear least square
2. Linear approaches
   a. Linear least square
   b. Weighted linear least square
   c. Subspace

3.2.1 Nonlinear scheme of Estimation:

When a pair of sensors that are deployed at a certain distance receives the same signal but with some timing difference, it is known as TDOA. This implies that clock synchronization across all receivers is mandatory. After all, the TDOA scheme is easier compared to the TOA method as it requires the time synchronization between the source and the receivers, which leads to an increase in hardware cost. Similar to the TOA, multiplying the TDOA by the known propagation speed leads to the range variation between the source and two receivers. Basically each noise - free TDOA defines a hyperbola where the source should lie in the 2 - D space. When a pair of hyperbolas intersect each other at a certain point, that point is said to be the location of the source. When there an existence of noise, we estimate x from a set of hyperbolic equations converted from the TDOA measurements.

3.2.2 Linear scheme of estimation:

In this research work, the basic concept of making use of linear localization schemes is to convert the nonlinear expressions of time of arrival localization scheme into equivalent linear equations having zero-mean disturbances with negligible errors in range measurement. Now after transformation, the optimization cost function turns out to be a uni-model assuring in getting global optimized solution for precise localization. The approaches like linear least square, enhanced weighted linear least square and subspace estimator have been employed for localization in this current research.

IV. TDOA ESTIMATION TECHNIQUE:

4.1 *Generalized Cross-Correlation Methods*

For solving the TDOA estimation problem, the conventional correlation techniques have been employed which were referred as the Generalized Cross-Correlation methods. The pre-filtered signals that are received at a pair of receiving stations are cross correlated using Generalized Cross-Correlation methods. Estimate the TDOA D between the two stations as the location of the peak of the cross-correlation estimate. Pre filtering is advised in order to emphasize the frequencies for which Signal-to-Noise Ratio (SNR) is the highest and attenuate the noise power before the signal is passed to correlate.

V. ACCURACY MEASUREMENT

5.1 *Comparison of MSE with CRLB:*

One of the most common method of measuring the accuracy of a PL estimator is by comparing the MSE with CRLB. The equation that is used for computing the MSE of a 2-D position location is MSE= $\varepsilon = E[(x - x1)^2 + (y - y1)^2]$,where (x; y) are the source coordinates and (x1; y1) is the estimated position coordinates of the source .In order to assess the PL estimators accuracy, the calculated MSE is to be compared with the theoretical MSE based on Cramer-Rao Lower Bound.

VI. SIMULATION RESULTS :

The MSPE is computed based on 1000 independent runs. The NLS and ML estimators are realized by the Newton –Raphson scheme. Figure shows the MSPEs of the two schemes at SNR ∈ [− 10, 60] dB Note that the decibel scale is employed in both axes to facilitate the presentation. As expected, the ML estimator is superior to the NLS method and the former MSPE is smaller by around 1 dB at SNR ∈ [10, 60] dB

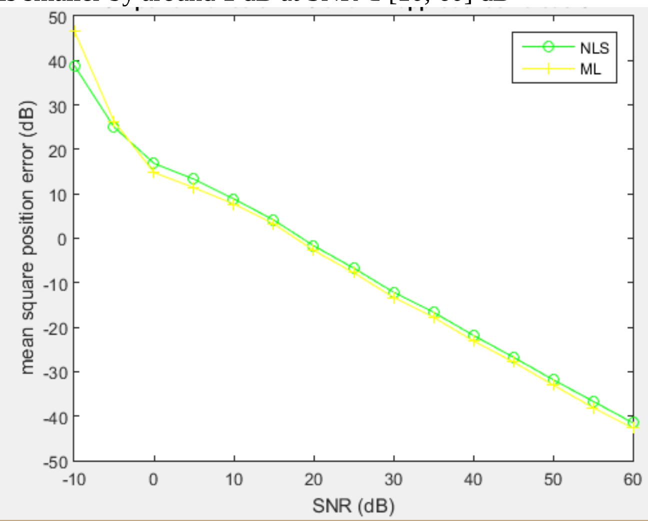

Figure 2. MSE performance of ML and NLS approaches vs SNR

There are three main parts in the program, namely, generating range measurements, position estimation using the NLS estimator, which is realized by the Newton – Raphson, Gauss – Newton, and steepest descent methods, and displaying results. Figures show the estimates of *x* and *y*, respectively, versus the number of iterations at SNR = 30 dB The initial guess is chosen as **x** ˆ 0 = [3 2]*T*, and the step size of the steepest descent method is μ = 0.1. Although all schemes provide the same position estimates upon convergence, it is observed that the Newton – Raphson and Gauss –Newton methods converge in around 3 iterations, while the steepest descent algorithm needs approximately 15 iterations to converge. Note that in the presence of noise, **x . x'** in a single trial, although *E* {**x**ˆ} = **x** for small error conditions xˆ 0 = [3 2]T. Similar to the NLS approach, all schemes provide the same position estimates upon convergence, but the Newton – Raphson and Gauss – Newton methods converge faster than the steepest descent algorithm. Nevertheless, it is difficult to see that the ML estimator is superior to the NLS approach in terms of positioning accuracy based on a single run.

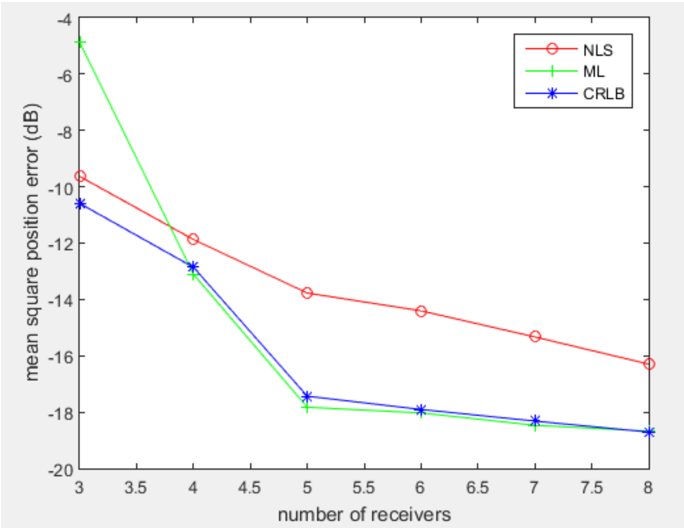

Figure 3. Nonlinear approach

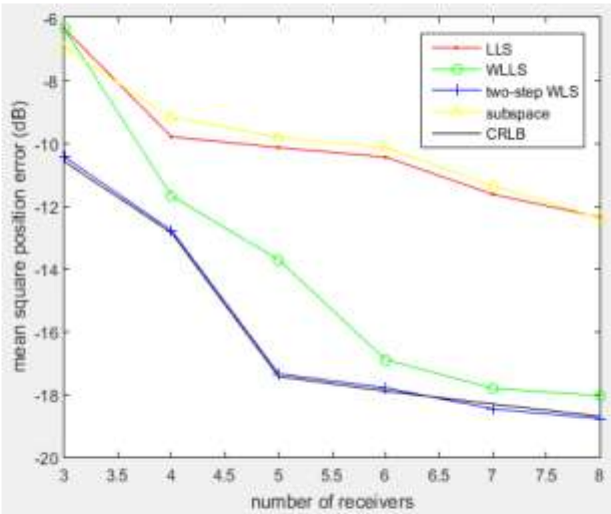

Figure 4.Linear approach

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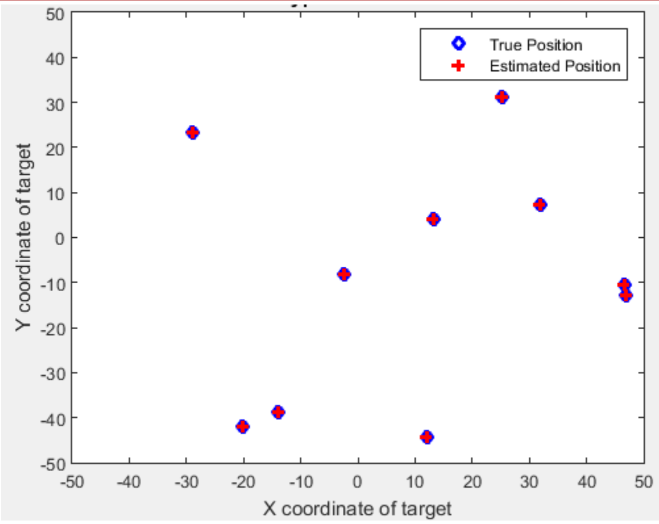

Figure 5. TDOA Hyperbolic Localization

Passive source localization using TDOA measurements has been addressed. After introducing the measurement signal models and their positioning principles, the nonlinear and linear approaches for determining the source location, which include the NLS, ML, LLS, WLLS, and subspace estimators, are presented. Similar to the NLS approach, all schemes provide the same position estimates upon convergence, but the Newton–Raphson and Gauss–Newton methods converge faster than the steepest descent algorithm. Nevertheless, it is difficult to see that the ML estimator is superior to the NLS approach in terms of positioning accuracy based on a single run. The nonlinear approach solves the nonlinear equations directly constructed from the TDOA, RSS measurements, while the linear methodology converts the nonlinear equations to be linear. Moreover, mean and variance analysis for a class of position estimators, which correspond to an unconstrained optimization problem, as well as CRLB computation are provided. In the presence of zero-mean Gaussian measurement errors, the estimation performance of the ML and constrained WLLS methods can achieve the CRLB, while the remaining estimators can only provide suboptimal localization accuracy.

VII. CONCLUSION

Passive source localization using TDOA measurements has been addressed. After introducing the measurement signal models and their positioning principles, the nonlinear and linear approaches for determining the source location, which include the NLS, ML, LLS, WLLS, and subspace estimators, are presented. Similar to the NLS approach, all schemes provide the same position estimates upon convergence, but the Newton–Raphson and Gauss–Newton methods converge faster than the steepest descent algorithm. Nevertheless, it is difficult to see that the ML estimator is superior to the NLS approach in terms of positioning accuracy based on a single run. The nonlinear approach solves the nonlinear equations directly constructed from the TDOA, RSS measurements, while the linear methodology converts the nonlinear equations to be linear. Moreover, mean and variance analysis for a class of position estimators, which correspond to an unconstrained optimization problem, as well as CRLB computation are provided. In the presence of zero-mean Gaussian measurement errors, the estimation performance of the ML and constrained WLLS methods can achieve the CRLB, while the remaining estimators can only provide suboptimal localization accuracy.

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