# Location Finding Sensors Using TDOA

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**Abstract- Emitter Localization using TDOA is a system that enables one to find the location of all the transmitters in the surroundings communicating with the frequencies of HF band. The time difference of arrival of the radio wave corresponds to the range difference from the transmitter to a pair of sensors or receivers and the emitter location lie on the hyperbola corresponding to this range difference. The system is totally passive and the Location Fix (LF) is done without the knowledge of the transmitter. Such a system has extremely valuable military and civilian applications. The systems comprises of a number of sensors geographically separated over an area and are interconnected through a communication network for transferring the received signal's snapshot data to a central unit where certain signal processing operations are done for obtaining the TDOA and LF. This paper deals with the design aspects of such a system, subsystems and signal processing modules. TDOA based LF algorithms, summary of Matlab simulation results were presented.**

**Key words: TDOA, FDOA, Emitter Location, Location Fix, Deployment scenario, correlation, Time synchronization, DDC**.

## I. INTRODUCTION

Presently, there are many different technologies used in position detection. But, as signal receiver operating in different locations is used to detect precise positions of objects located at long distances, it is hard to know when an object's or user's-terminal devices send a signal. In this case, the technology using the TOA (Time of Arrival) is impossibly unreliable, and the TDOA (Time Difference of Arrival) technology is a more suitable option.

The sensors are tuned to the signal of one of these emitters, snap shot of the received signal is captured simultaneously and in time synchronism by all the sensors. Since the arrival time at each sensor is going to be different one can measure

this Time Difference Of Arrival TDOA by suitable digital signal processing. TDOA of a radio signal measured at three or more receiver sites can be used to locate the position of an RF transmitter (emitter). The system comprises of number of sensor receivers geographically separated over a distance whose locations are known and are interconnected through data communication links for transfer of received signal snap shot (SS) data. The snap shot data is collected at each sensor with highly accurate time synchronization. One of these sensors is designated as reference station for obtaining the TDOA with respect to other sensor stations.

In the following paragraphs dual band TDOA based emitter location system is described. The design of sensor unit covers for multiple RF bands out of which two signals belonging to two different bands can be simultaneously captured.

The salient features of this type of RF emitter location system are:

System covers wider 2D and 3D space

Direct location fix – no necessity of DF receivers

RF system consists of simple tuner and I/Q data generation

Antenna required is omni

Higher operating sensitivities

Can handle all types of modulations

Built-in high speed communication and networked operation

## II. TDOA

TDOA 'τ' is a result of difference in the path length or range between transmitter(Tx) and receiver(Rx) sites, and therefore corresponds to propagation time difference between the Tx and a pair of Rx sites.

$\tau$ = (range difference)/c , where c velocity of propagation.

Measurements of $\tau$ define contours of LOPs (Lines Of Position). Contours of constant TDOA for a given pair of receivers are shown in Fig (1).

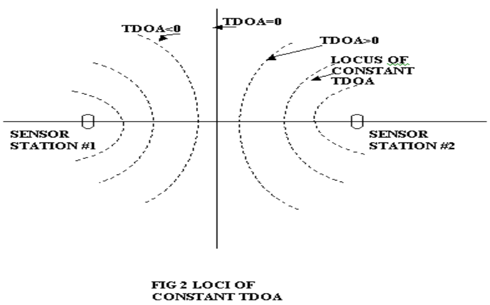


Figure 1 Contours of constant TDOA

Ideally, intersection of two such contours can establish emitter's location. In practice, equations are formed with the TDOA measurements from several pairs of receivers,

which are then used for estimating the emitter position or the Location Fix (LF).
TDOA estimation methods aim at estimating the differential delay as accurately as possible.

*1. Correlation*

Correlation of signals is the basis of estimating time difference of arrival algorithms. Independent processing algorithm to estimate the TDOA makes use of time correlation. Mathematically the discrete time correlation equation is represented by

$$R_{xy}(k) = \sum_{t=-\infty}^{+\infty} x(t)\, y^*(t+k)$$

for t= -N to N-1, where N is the length of signal snapshot. The signal $R_{xy}$ (k) is called the cross correlation function of x (t) and y (t), *denotes the complex conjugate. Since $R_{xy}$ (k) is a measurement of similarity between x (t) and y (t), it will reach its maximum for a particular value of k corresponding to greatest similarity. If x (t) and y (t) are time shifted of the same signal $R_{xy}(k)$ will reach its maximum when k is equal to the delay between the two signals.

## III . TIME SYNCHRONIZATION

Time synchronization involves both clock and TOD (Time Of the Day) synchronization at several geographically separated locations to the desired accuracy.
Since the TDOA based position location system is dependent on time difference measurements, it calls for highly accurate time synchronization and time tagging of the snap-shot data. This goes down to nanoseconds range. However, keeping in mind the practical implementation aspects we may be constrained to restrict the timing 1σ error to about 25-50 nS. With this timing accuracy, reasonable positional accuracy can be obtained with the sensor station separations > 2 KMs.
The Clock & Time Sync block is the heart of the system and it basically consists of two parts (a) Clock and Timing source (b) Synchronization hardware circuit. This block provides the time synchronization to the desired accuracy needed for the system. The Time sync can be GPS based or non-GPS based. GPS based method has to be resorted to when data communication is to depend on public or some other data network which is not part of this system. GPS is also essential subsystem to get the accurate coordinates of sensor stations. A hybrid approach incorporating both GPS and non-GPS is advantageous. Now-a-days equipments called Precision Time Protocol (PTP) sync servers are commercially available having built-in highly stable OCXO or Rubidium clock with GPS backup. PTP time Sync master server located at central station and PTP slave devices at sensors use IEEE 1588 protocol function provides the required time synchronization with accuracies of 40 nS.

## IV. LF ALGORITHMS

Several papers were reported in the literature containing algorithms for the estimation TDOA based LF of a transmitting source or the emitter location. Matlab simulation results on some of these algorithms with regard to their performance against RMS range difference error variance are discussed below.

*1. Taylor series algorithm*

In Taylor series method [1], the measurement equations are linearized through Taylor series expansion by keeping terms below second order. Starting with an initial guess of the location, an iterative procedure is used which leads to the correct solution. The algorithm improves the guess step by step by determining the least sum squared error correction. The disadvantage of this method is that it requires an initial guess point. There is no guaranty that it will converge to a correct solution point. Moreover, we have to do several iterations every time. Hence this method also requires considerable amount of computational time.

*2. Schau Algorthm*

Unlike the Taylor series where there is no guaranty for obtaining the solution, Schau algorithm [2] results in a closed form solution for emitter location using TDOA measurements from multiple sensors employing the principle of intersecting spheres instead of hyperboloids. There are no iterations and thus computational time is very short.

*3. Mellen Algorithm*

Mellen [3] algorithm is also a closed form solution similar to that of Schau algorithm to obtain source location. It is a direct and short derivation based on the closed-form solution of the nonlinear equations for emitter location using TDOA measurements.

*4. Ho Xu Algorithm*

The Ho & Xu algorithm [4] gives an attractive closed form solution to the emitting source position through TDOA measurements. The algorithm can also take Frequency Difference Of Arrival (FDOA) data and give emitter velocity estimate as output. FDOA is because of difference in Doppler frequency in case of mobile emitters. In case either the FDOA measurements are not available or the emitters are static, the appropriate terms are set to zero in the algorithm, using only the TDOA inputs.

First, a set of TDOA measurement equations are formed. These equations are squared and time derivative is then taken and a second set of equations are formed using the FDOA measurements. The measurement equations are transformed into a set of linear equations by introducing nuisance parameters. It then solves the source location, velocity and the nuisance parameters by weighted least squares minimization. Next the nuisance parameters are eliminated through the use of another least squares minimization to further improve position estimate. This solution is computationally efficient and does not suffer from convergence problem. This algorithm is more generic in nature catering for 2 or 3 dimensional static & mobile transmitting source and sensors.

## V. SYSTEM DESCRIPTION

Fig (2) shows the block diagram of TDOA based emitter location system consisting of 4/5 sensor stations and one central station.

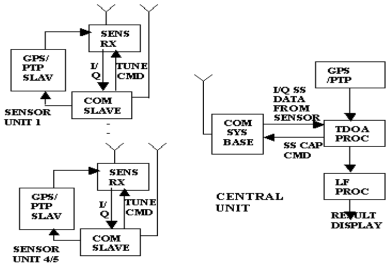


Figure 2 System block diagram

Each one of these sensor stations are equipped with (a) sensor receiver (b) GPS/PTP slave and (c) PMP communication slave equipment shown in Fig (2).

The central station software can be implemented in a PC or laptop. The central station is required to prepare a list of signals of interest for which emitter location is to be carried out. One of the signals from the list along with other required parameters is sent on the communication link as LF capture command to all sensor stations simultaneously. The base station of PMP communication equipment is kept at the central station to collect the SS data from all sensors. Accurate position coordinates from all the sensors is obtained by sending appropriate command.

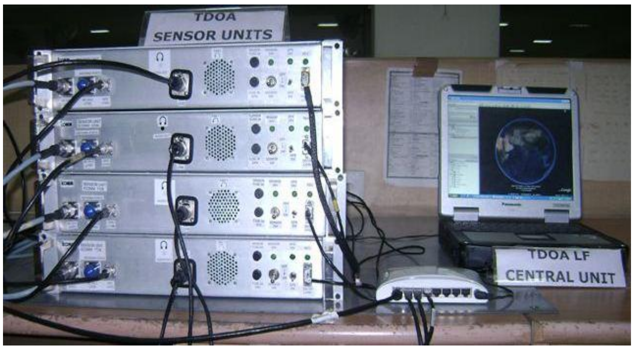


Figure 3 TDOA based LF System

Photograph of TDOA based LF system designed and developed by M/S ICOMM Tele Ltd, Hyderabad, consisting of 4 sensors and one central unit is shown in Fig (3)

## VI. SUBSYSTEMS

The system contains the following subsystems:

At Sensor Stations

(a) Sensor receiver
(b) GPS/PTP time synchronization unit
(c) Communication slave node

At Central Station

(a) Communication Base (master) node
(b) GPS and PTP master
(c) Central unit processing PC or laptop

## VII.THE SENSOR UNIT

The sensor unit is the most important part of TDOA based LF system. Essentially this is remotely controlled digital receiver covering the desired RF frequency bands. The design caters for 2 RF bands and 2 DDC capture channels. This unit is connected to communication equipment through standard Ethernet port.

Block diagram of the sensor unit and brief description of its functionalities are given in Fig (4). It has two sections viz., the RF section

and the Digital section.

The RF section catering for HF band 2-30MHz and VHF band 30-178MHz. The RF section consists of 3 RF modules for each band (i) Tuner (ii) RSS & VGA and (iii) synthesizer. The first module contains low noise front end amplifier along with 7 pre selection sub-band filters covering each band. The second module contains Variable Gain Amplifier along with second set of filters. It also contain Receive Signal Strength (RSS) measurement channel working parallelly. The third module contains DDS based synthesizer to generate the required LO frequency used for producing 70 MHz IF either by up or down conversion.

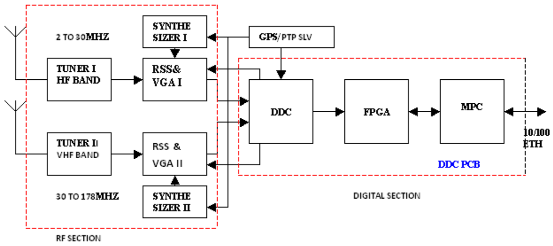


Figure 4 Sensor unit

The digital section of the sensor unit caters for simultaneous handling of two RF channels. It takes the RF input from the RF section and carries out fine tuning, Digital Down Conversion to obtain base band I/Q data and receiver gain control operation. Micro Processor MPC interfaces to external equipment through standard Ethernet port. The MPC controls the selection of filter and synthesizer frequency corresponding to the frequency of the desired emitter signal. DDC block performs fine tuning and sets the BW corresponding to the desired signal and capturing of the I/Q data corresponding to the signal snap shot. The FPGA takes I/Q data delivers to the MPC. It also sets gain of the receiver based on the RSS.

Sensor unit also contain built in GPS/PTP slave module which is used for providing accurate and stable reference clock source.

The sensor unit gets SS capture commands from the central unit through the Ethernet port. It collects the relevant data with accurate time synchronism derived from GPS/PTP and sends the same as reply packets to the central unit.

## VIII. THE CENTRAL UNIT

Block diagram of the Central unit is shown in Fig (5). The hardware at the Central Unit consists of a PC or laptop

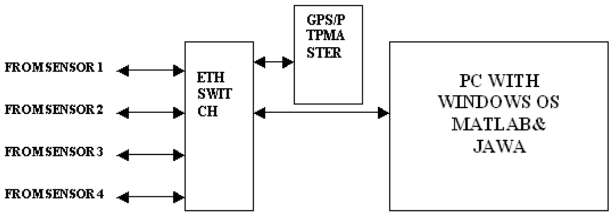


Figure 5 Central unit block diagram for LF system

The data transfer between the central unit and the Sensor units is done through the Ethernet port. Gigabit Ethernet switch is used for connecting data links to various entities. Data is taken from 4 sensors depending on the area of operation for carrying out the LF function. Sensor station positional coordinates are obtained using GPS. These are generally given as Lat-Lon (WGS-84) which are converted to Cartesian (UTM) using coordinate transformation software.

The functions of central unit with regard to LF operation are given below.

- (i) Message & Data transfers with sensors through Ethernet port via com equipment
- (ii) Data conversions, validation, time alignment
- (iii) TDOA processing
  - (a) Interpolation
  - (b)Correlation
- (iv) LF processing
- (v) LF result display

The signal processing functions for TDOA and LF are done in 2 ways using Matlab & Java

## IX. TDOA SYSTEM LF ACCURACY

### *1. TDOA system LF Accuracy Simulation Results*

Extensive Matlab simulation has been carried out changing the (a) sensor deployment geometry (b) Emitter locations distributed over large geographical area (c) emitter signal BWs (d) S/N ratios

Firstly, out of the two sensor deployment patterns viz., Quadrilateral & Y-Types, it was found Y-Type deployment pattern gave better results compared to quadrilateral type.

Further simulations were done using two Y-Type deployment patterns having average sensor separation distances approximately (a) 2KMs and (b) 9KMs. Emitter locations were selected on range circles at 10deg intervals. Range circle radii w.r.t center of deployment used are (a) 2,4,6,8 KMs for short-Y (b) 5,10,20,30 KMs for long-Y. Signal BWs simulated were (i) 4to10KHz, (ii) >20 KHz, (iii)>100 KHz, (iv)>1MHz and corresponding S/N ratios 30, 20, 10, 0 dB respectively.

The overall RMS Lf error has been computed for 4x36=144 readings for each signal BW are shown in Tables (1) & (2).

Table 1. Short Y-Type deployment - Maximum range circle radius 8KMs:

| SIGNAL BW | MIN S/N | LF RMS ERROR (KM) |
|---|---|---|
| Narrow band (4 to 10KHz) | 30dB | 0.8041 |
| BW >20 KHz | 20dB | 0.8900 |
| BW > 100KHz | 10dB | 1.3171 |
| BW > 1MHz | 0dB | 0.6672 |

Table 2. Long Y-Type deployment - Maximum range circle radius 30KMs:

| SIGNAL BW | MIN S/N | LF RMS ERROR (KM) |
|---|---|---|
| Narrow band (4 to 10KHz) | 30dB | 2.2045 |
| BW >20 KHz | 20dB | 1.4880 |
| BW > 100KHz | 10dB | 2.1851 |
| BW > 1MHz | 0dB | 1.0201 |

Based on these simulation studies, the following conclusions were drawn on the achievable LF accuracy for the TDOA based emitter location system.

The maximum range of operation is 3 times sensor separation kept from the center of deployment configuration. Minimum S/N required was 30 dB for narrow band, 20dB for medium and 10 to 0dB for wider bandwidth signals.

The overall LF RMS accuracy when the readings are taken over large number emitter locations spread uniformly over the area covered by the maximum range circle found to be 10% of max range and >50% readings will be within this accuracy.

### *2. Accuracy Improvement For Narrow Band Signals*

In HF or VHF bands, we usually encounter narrow band analog AM & FM modulations having RF bandwidths of 8 KHz. By its very nature, the TDOA accuracy is poor for narrow band signals especially for AM signals. In order to get reasonable accuracies for narrow band signals require SNR >30 dB.

Matlab simulation studies showed using the following techniques one can obtain desired TDOA and consequent LF accuracies even at 10 dB SNR

(i) Using direct RF for digital down conversion

(ii) Interpolation technique, in which correlation operation is done at higher sampling rates of the order of 10Ms/s, the interpolation factor r = round ($10^7$ / Fs), where Fs is sampling rate of signal samples.
(iii) Offset carrier technique in which correlation is done on modulated signal rather than base band signal.
Results of simulation which demonstrate the improvement for narrowband AM and FM signals using the offset carrier technique can be seen in the figures (6) to (7). In these figures '*' indicate the sensor, 'o' indicate actual emitter position and '+' indicate the estimated position obtained after LF processing.

In Fig(6) using offset carrier TDOA RMS error improved to 0.3084 µS & LF RMS error to 0.2635 KMs at S/N=10dB.

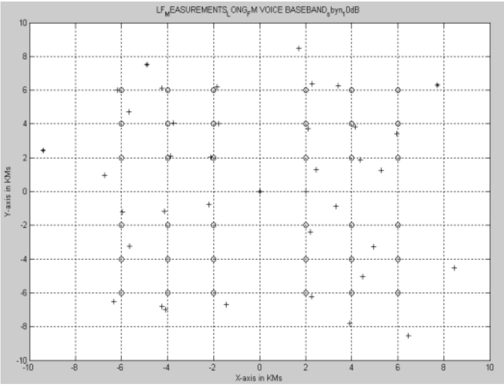


Figure 6 AM voice base band S/N 10dB

In Fig (7) using offset carrier TDOA RMS error improved to 0.2598 µS & LF RMS error to 0.2195 KMs at S/N=10dB.

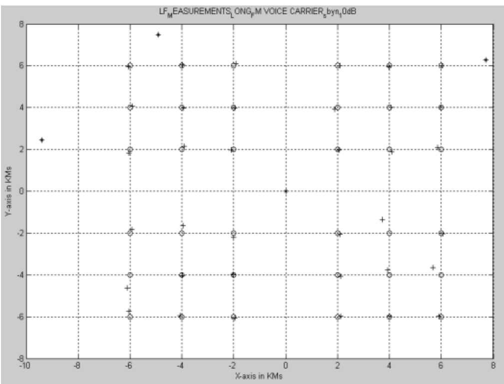


Figure 7 FM voice offset carrier s/n 10dB

## X. TDOA SYSTEM SPECIFICATIONS

Sensor Unit:
Freq coverage: 2MHz to 178 MHz
Receiver sensitivity: -105 dBm, 10 KHz BW, 10 dB S/N
Noise Figure : 12dB
Dynamic range: 70 dB
Gain control : MGC & AGC 55dB
Antennae: (i) Vertical monopole 2-30MHz
(ii) Broadband discone vertical pol 30-200MHz
Instantaneous BW: HF 1-8 MHz
VHF 20 MHz
Signal bandwidths : 4 KHz to 800 KHz
No. of simultaneous bands/channels: Two
Type of signals handled : FF, Burst
Data capture memory: 256K I/Q samples
GPS 1PPS time accuracy: 15 nS (1σ)
Network interface: 10/100 Ethernet TCP
Operating Temp: -10 to +55 $^0$C
Dimensions: 422.6 x 450 x 88 mm (2U LRU)
LF accuracy: Discussed in section IX

Central unit:
Hardware: PC or Laptop
Ethernet switch
Software: Command & control of sensors
TDOA computation
LF computation
GUI & Display processing

## XI. CONCLUSION

RF emitter location system utilizing Time difference of arrival between pairs of sensor receivers is presented. Requirements of the communication subsystem, TDOA measurement, time synchronization accuracies needed were specified from practical system implementation point of view. TDOA accuracy improvement techniques for narrow BW signals were given. A generic TDOA based location fix algorithm has been identified which can be used for static and mobile 2D & 3D scenarios. Important results extracted from the extensive Matlab simulation studies carried out on the LF accuracy of TDOA based system were brought out. It is shown that using this technique one can get good accuracies of emitter position, cover wider geographical areas using moderate sensor separation lengths. The system offers highly promising and implementable solution to the communication signal emitter location problem.



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