Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 6(1): 43- 48
© Scholarlink Research Institute Journals, 2015 (ISSN: 2141-7016)
jeteas.scholarlinkresearch.com

Performance Evaluation of Correlative Interferometry for Angle of Arrival Estimation

Suhail M. Kamal[1], Ashraf A. Adam[2], Abimbola S. Ajagun[2]

[1]Center for Information Technology (CIT),
Bayero University, Kano, Nigeria
[2]Department of Electrical and Electronics Engineering,
Federal University of Technology, Minna, Nigeria
Corresponding Author: Ashraf A. Adam

Abstract

The paper proposes the implementation of correlative interferometry for angle of arrival (AOA) estimation. The correlative interferometry processing involves the comparison of the measured phase differences between the antenna elements of the direction finder (DF) antenna system with those obtained for the same antenna system at all possible directions of incidence. The comparison is made by calculating the correlation of the two data sets obtained by multiplying the coordinates element by element and summing the result. Using different comparison data sets for different wave directions, the bearing is estimated from the data set for which the correlation is at a maximum. Four and eight uniform linear array (ULA) configuration of the algorithm is investigated so that that the amount of processing and memory was optimized with accuracy in the measurement of the direction. From the optimum structure, Monte Carlo simulation is carried out to evaluate the mean and variance of multiple AOA estimates for various signal-to-noise ratios (SNR). Results obtained shows that eight element ULA performs better than the four element ULA due to its higher resolution, with earlier having an average AOA estimate of 10dB and the latter of 12dB. This paper caters for the high processing burden associated with direction finding, provides a significant relationship between the number of ULA elements, resolution and effect of noise in AOA estimation for direction finding. This paper presents a critical evaluation on the superiority of correlative interferometry for AOA estimation.

Keywords: correlative interferometry, angle of arrival (AOA), direction finder (DF), uniform Linear Array (ULA), Monte Carlo

INTRODUCTION

A radio direction finding (RDF) system is a passive device needed in various application fields such as navigation, military intelligence, radar, astronomy, sonar, wireless adhoc network, mobile communication systems, cognitive radio networks through determination of the angle of arrival (AOA) of an incident wave (Ueda, T. et al., 2003; Xueli Sheng et al., 2009; Zimmermann, L. et al., 2012; Abdalla, M.M. et al., 2013; Elhag, N.A.A et al., 2013). The AOA is mainly determined by one of three methods: amplitude response, time delay, or phase difference. There are several methods based on direct evaluation for radio direction finding; Watson Watt/Adcock method, Differential Doppler, Directional Antenna and Correlative Interferometry. The Watson-Watt DF technique falls into the amplitude-comparison DF technique category. The Differential Doppler algorithms are single-channel algorithms that produce an AOA estimate based on phase of the received signal, while in the directional DF method, the bearing is derived from the characteristic of the receive voltage as a function of the antenna rotation angle (Rohde & Schwarz, 2011).

Existing direction finders tends to give error due to multipath fading and mutual coupling of antenna elements which results in ambiguities on estimating the AOA and also gives high error in the presence of noise. There is also high processing burden accrued from implementing one big look-up table of all possible direction and therefore a need for a robust, flexible and more accurate technique for estimating the location of emitters. The correlative interferometer has been identified as having a high accuracy of measurement (Cheol-Sun Park ; Dae-Young Kim, 2006), it involves the comparison of the measured phase differences between the antenna elements of the direction finder (DF) antenna system with those obtained for the same antenna system at all possible directions of incidence. The comparison is made by calculating the scalar product of two vectors obtained by multiplying the coordinates element by element and summing the result. Using different comparison data sets for different wave directions, the bearing is estimated from the data set for which the correlation is at a maximum.

Various popular DF algorithms based on array signal processing such as the MUltiple SIgnal Classification (MUSIC) algorithm (Mewes, H. et al., 1994), expectation-maximization (EM) approach (Sadler, B.M. et al., 1999), fast maximum likelihood estimation (FMLE) (Tien-Ho Chung ; Cheung, J.Y., 1994) and many others have been developed since the existence of array signal processing. Each caters for some problem(s) associated with Radio DF, but also associated with shortcomings with high processing burden being the most common among them. This short coming accounts for the main objective this work. The correlative interferometer used in this work is based on linear array antenna arrangement and a passive single platform source locator equipped with the sensor arrays. Its algorithm was designed using a uniform linear array (ULA) that provides 180 degrees angle coverage for angle of arrival (AOA) estimation of all incident narrowband RF signals. The algorithm was partitioned into 2 levels: coarse scan and fine AOA estimate to cut down processing burden. Finally, the performance was evaluated using 4 and 8 element ULA AOA estimation in the presence of noise to compare their accuracy and present an objective conclusion. However it is imperative to mention that the algorithm designed is limited to linear antenna configuration and single AOA estimate at a time.

METHODOLOGY

Recent related work has used Canonical Correlation Analysis (CCA) of also low computational complexity to cater for the time-delay direction finding sensitivity to interference (Gaoming Huang et al., 2005).The method achieves 100 percent correct estimate at SNR of 14dB. This work extends introduces the interferometer method involved in the development of the algorithm for estimating the AOA, after generation of the signals. First of all, steering vectors of the antenna array for various angle of arrival is calculated, then the look up table of phase differences are implemented and finally correlation function on measured steering vectors and lookup table data sets is applied. Its look up table is partitioned into two levels; the first for the coarse scan and the second for the fine scan thereby cutting down the processing burden. Sections of this method are presented in the upcoming sub-sections.

Uniform Linear Array Antenna

Consider an M-element uniformly spaced linear array (H. Oraizi and M. Fallahpour, 2008) which is illustrated in Figure 1. The array elements are equally spaced by a distance d, and a plane wave arrives at the array from a direction off the array broadside. The angle is called the angle-of-arrival (AOA) of the received signal, and is measured clockwise from the broadside of the array. In this work, 4 and 8 element uniform linear antenna array arrangements are considered.

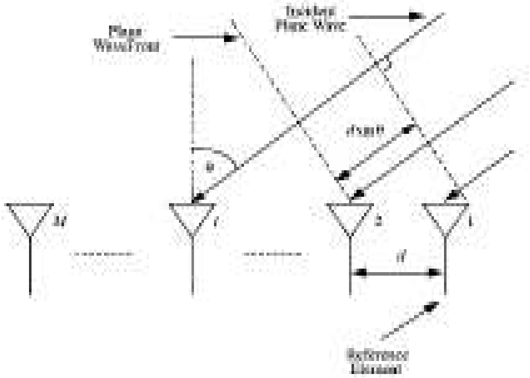


Figure 1. Illustration of a plane wave incident on a Uniformly Spaced Linear Array Antenna from direction θ

Steering Vector

A steering vector that has a dimension equal to the number of elements in the antenna array can be defined for any antenna. It contains the phases of the signal at each antenna element relative to the phases of the signal at the reference element (element 1). The steering vector achieves an angular dependence due to the different array response for each direction. The array geometry defines the uniqueness of this association and for an array of identical elements; each component of this vector has unit magnitude. The phase of its *n*th component is equal to the phase difference between signals induced on the *n*th element and the reference element due to the source associated with the steering vector (Jeffrey Foutz et al., 2008). The reference element usually is set to have a zero phase

Signal Generation

Consider the signal to be the complex sinusoidal signal; the signal received by the reference element antenna and is given by equation (1).

$$S_1(t) = e^{j2\pi f_0 t} \qquad (1)$$

From Figure 1, the received signal by the second element of the antenna array will be the delayed version of the signal received by the first element. Consider the delay occurred be ‘τ’. Hence, the signal at the second element is given by;

$$S_2(t) = S_1(t-\tau) = e^{j2\pi f_0 t}.e^{-j2\pi f_0 \tau} \quad (2)$$

Delay time, ‘τ’ is given by,

$$\tau = \frac{dsin\theta}{c} = \frac{dsin\theta}{f_0\lambda_0} \quad (3)$$

On substituting eqn (2) in eqn. (3), we get,

$$S_2(t) = e^{j2\pi f_c t}.e^{-j2\pi f_0 \frac{dsin\theta}{f_0\lambda_0}}$$

$$= e^{j2\pi f_0 t}.e^{-j2\pi \frac{dsin\theta}{\lambda_0}}$$

$$= e^{j2\pi f_0 t}.e^{-j\phi} \quad (4)$$

where,

$$\phi = \frac{2\pi dsin\theta}{\lambda_0} \quad (5)$$

Therefore,

$$S_2(t) = S_1(t)e^{-j\phi} \quad (6)$$

If $n(t)$ is the noise affecting the signal, then the total signals received by the antenna array elements vector form is;

$$\begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \\ \vdots \\ x_m(t) \end{bmatrix} = S(t)\begin{bmatrix} 1 \\ e^{-j\emptyset} \\ e^{-j2\emptyset} \\ \vdots \\ e^{-j(m-1)\emptyset} \end{bmatrix} + \begin{bmatrix} n_1(t) \\ n_2(t) \\ n_3(t) \\ \vdots \\ n_m(t) \end{bmatrix} \quad (7)$$

i.e.,

$$x(t) = \sum_{i=1}^{M} a(\phi_i)S_i(t) + n(t) \quad (8)$$

Correlative Interferometry Algorithm

The basic principle of the correlative interferometer entails a comparison of the measured phase differences with the phase differences obtained for a DF antenna system of known configuration at a known wave angle. The comparison is done either by calculating the quadratic error or forming the correlation coefficient of the two data sets (Rohde & Schwarz, 2011). If different azimuth values of the comparison data set are used, the bearing is obtained from the data for which the correlation is at a maximum.

In this work, algorithms were developed both for 4 and 8 element antenna array with an angular coverage of 180^{c} i.e. from $-{}^{\pi}/_{2}$ (-90^0) to ${}^{\pi}/_{2}$ (90^0). The angle of arrival estimate is divided into 2 sections; first it performs a coarse estimate of a resolution of ${}^{\pi}/_{8}$ (22.5^{c}) to obtain the AOA. If maximum correlation is not obtained then the second level estimate of a resolution of ${}^{\pi}/_{64}$ (2.8125^{c}) is run to obtain the exact AOA.

RESULTS AND DISCUSSIONS

The Monte Carlo simulation depicts the response of a designed system when faced with uncertainty parameters and as such used in this work to examine the behaviour of the DF design from very low SNR to high SNR. The noise considered for this work is of zero mean, additive, complex stationary circular Gaussian random process and uncorrelated from snapshot to snapshot. At each SNR, the program is run for 100 loops. For each loop, the Correlative Interferometer algorithm is loaded, the varying variance is reflected on the signal, and the AOA estimation is carried out. At the end of the 100 loops, mean and variance of the AOA estimates at different SNRs are retrieved. For this work, two randomly selected 1st level estimates ($\frac{-16\pi}{64}$ and $\frac{16\pi}{64}$) and two 2nd level estimates ($\frac{-8\pi}{64}$ and $\frac{11\pi}{64}$) were considered. The plot of the results obtained both for 4 and 8 elements ULA are presented in Figure 3. It is important to point that all means of AOA estimates obtained are plotted in radians.

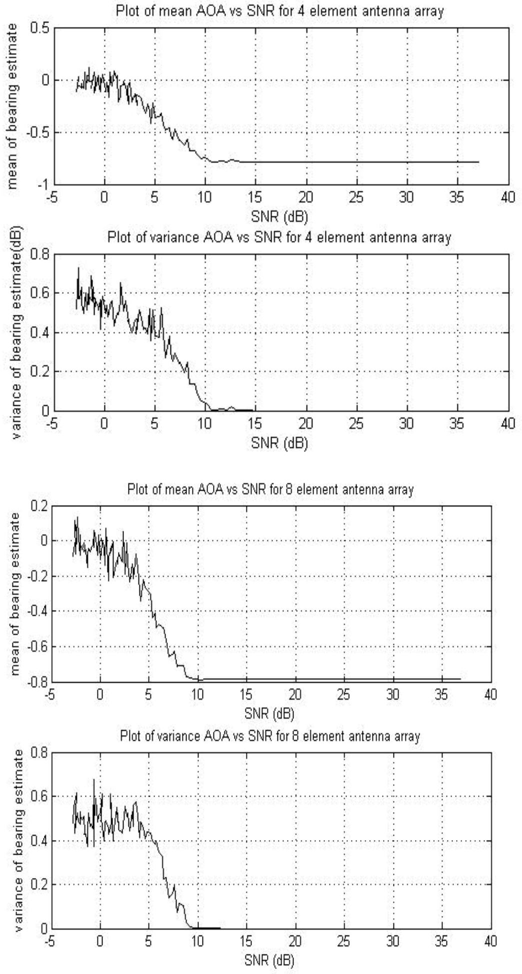


Figure 3a. Monte-Carlo result for angle -45^0 $(-{}^{16\pi}/_{64})$

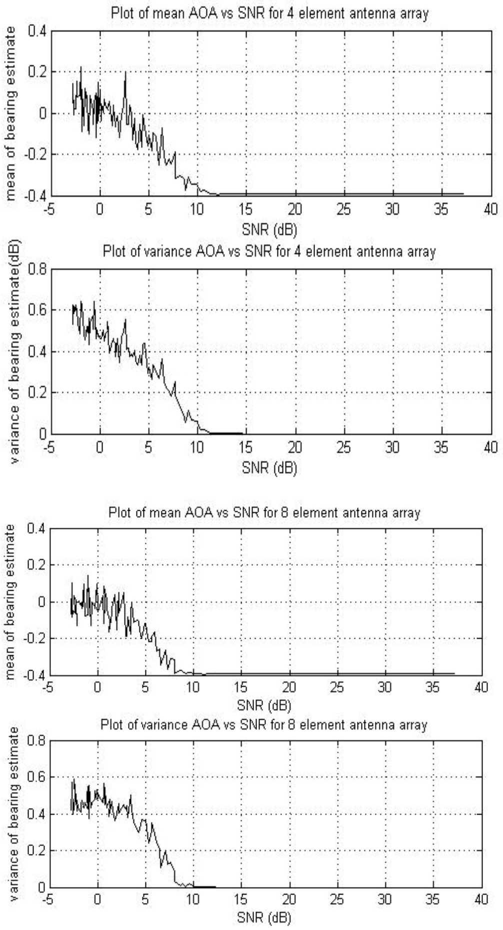
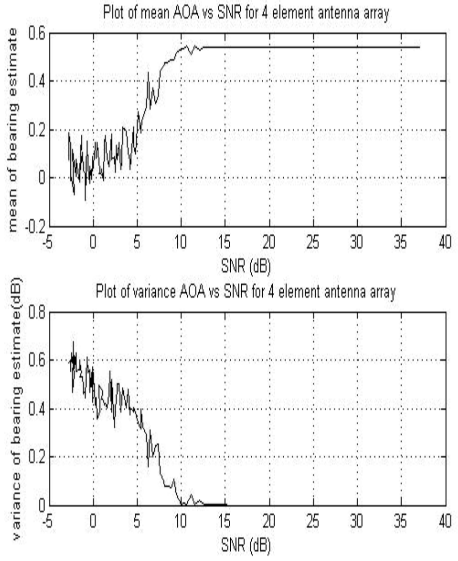


Figure 3b. Monte-Carlo result for angle -22.5^{c} $(-8\pi/64)$.



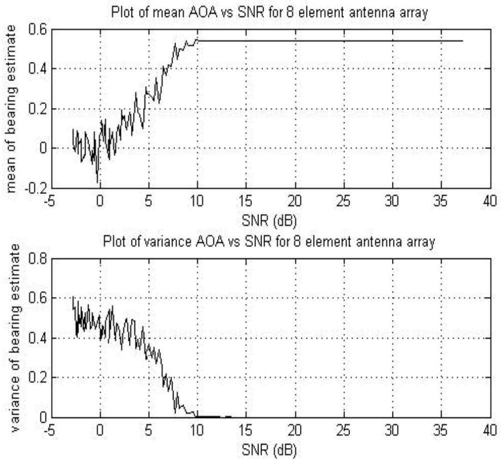


Figure 3c. Monte-Carlo result for angle 30^{c} $(11\pi/64)$.

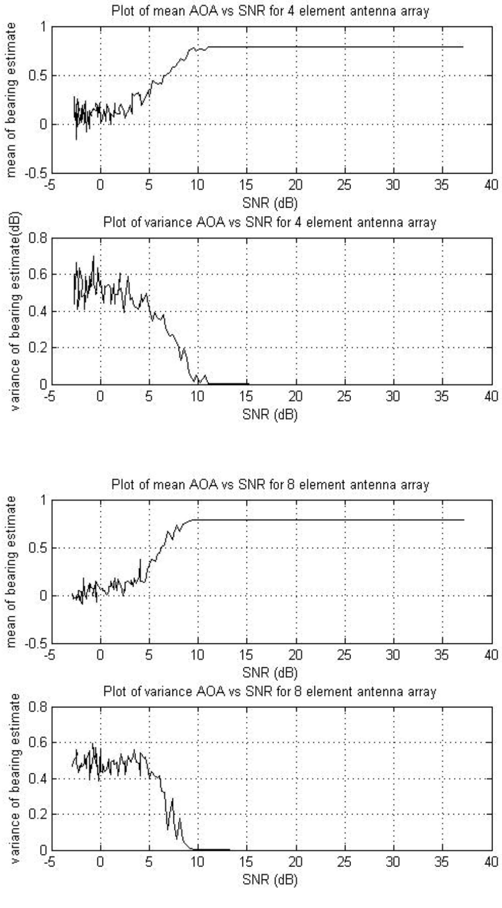


Figure 3d. Monte-Carlo result for angle 45^{c} $(16\pi/64)$.

From the above plot of results it can be seen that both the 4 and 8 element ULA have achieve a good and reasonable performance at a medium SNR. From figures 3a, it can be observed that for 4 element ULA estimates, correlation with the exact estimate starts at around 12dB SNR shown in the mean plot with its variance also getting zero at that particular point (zero variance indicates exact estimate achieved) while that of 8 element ULA the estimates starts at 10 dB SNR. This sequence is the same for the remaining results obtained with a slight difference in SNR. The results can be summarised in tabular form in Table 1 for the AOA estimates considered for these various angles and their corresponding threshold SNRs and level of estimation.

Table 1: SNR Threshold and Level of Estimation for some Various Angles

θ (rad)	$SNR_{Threshold}$ (Mean) dB		$SNR_{Threshold}$ (Variance) dB		Estimation Level
	4 ULA	8 ULA	4 ULA	8 ULA	
$\frac{-16\pi}{64}$	13	10.5	12.5	9.5	1st
$\frac{16\pi}{64}$	11	9.5	11	10	1st
$\frac{-8\pi}{64}$	14	10.5	11	10.5	2nd
$\frac{11\pi}{64}$	12	10	12	10	2nd

It is seen that using a higher number of elements in the ULA will achieve more performance as this sequence of lower SNR for higher elements ULA is the same for the estimates irrespective of estimation level. This theory goes in-line with previous work, where the performance increased with increased number of non-parallel antenna pairs (Kebeli, M., 2011) and the use of higher order modes for a biconical antenna (Svantesson, T., 2000).

CONCLUSION

The correlative interferometer algorithm for estimating the angle of arrival (AOA) was designed and developed for four (4) and eight (8) element uniform linear array. From the results obtained, it can be seen that an average peak performance of AOAs estimate at approximately SNR of 12dB and 10dB is gotten for the 4 and 8 elements ULA respectively. The SNR is reasonable when compared with previous related cited work. Hence it can be concluded that increasing the number of element in the ULA will enhance the estimate as naturally anticipated.

REFERENCES

Abdalla, M.M. ; Abuitbel, M.B. ; Hassan, M.A., Performance evaluation of direction of arrival estimation using MUSIC and ESPRIT algorithms for mobile communication systems, 2013 6th Joint IFIP Wireless and Mobile Networking Conference (WMNC), DOI: 10.1109/WMNC.2013.6549043. 2013, pg 1-7

Cheol-Sun Park ; Dae-Young Kim, The Fast Correlative Interferometer Direction Finder using I/Q Demodulator, Asia-Pacific Conference on Communications, 2006. APCC '06. DOI: 10.1109/APCC.2006.255915, pg 1-5

Elhag, N.A.A. ; Osman, I.M. ; Yassin, A.A. ; Ahmed, T.B., Angle of arrival estimation in smart antenna using MUSIC method for wideband wireless communication, 2013 International Conference on Computing, Electrical and Electronics Engineering (ICCEEE), DOI: 10.1109/ICCEEE.2013.6633909. pg 69-73.

Gaoming Huang ; Luxi Yang ; Zhenya He, Time-delay direction finding based on canonical correlation analysis, IEEE International Symposium on Circuits and Systems, 2005. ISCAS 2005. DOI: 10.1109/ISCAS.2005.1465859. pg 5409-5412

H. Oraizi and M. Fallahpour. Nonuniformly Spaced Linear Array Design for the Specified Beamwidth/ Sidelobe Level or Specified Directivity/Sidelobe Level with Coupling Considerations. Progress in Electromagnetics Research M, Vol.4, 185–209, 2008

Jeffrey Foutz, Andreas Spanias, and Mahesh K. Banavar. Narrowband Direction of Arrival Estimation for Antenna Arrays, Morgan and Claypool Publishers. 2008

Kebeli, M., Extended symmetrical aperture direction finding using correlative interferometer method, 2011 7th International Conference on Electrical and Electronics Engineering (ELECO). pg II-209 -II-213.

Mewes, H. ; Wolf, F. ; Luiken ter Haseborg, J., Experimental investigations on high resolution direction finding algorithms, AP-S. Digest on Antennas and Propagation Society International Symposium, 1994. Vol 3, DOI: 10.1109/APS.1994.408204, pg 1540-1543

Rohde & Schwarz, Direction Finders: Introduction into the Theory of Direction Finding in Radiomonitoring & Radiolocation | Catalog 2011/2012.

Sadler, B.M. ; Kozick, R.J. ; Moore, T., Performance analysis for direction finding in non-Gaussian noise, Acoustics, 1999 IEEE International Conference on Speech, and Signal Processing, 1999. Proceedings., Vol 5, DOI: 10.1109/ICASSP.1999.761358, pg 2857-2860

Svantesson, T., Multimode based direction finding, Conference Record of the Thirty-Fourth Asilomar Conference on Signals, Systems and Computers, 2000. Vol 1, DOI: 10.1109/ACSSC.2000.911024, pg 595-599

Tien-Ho Chung ; Cheung, J.Y., Direction finding estimation for linear chirp signal, 1994 Conference Record of the Twenty-Eighth Asilomar Conference on Signals, Systems and Computers, 1994. Vol 1, DOI: 10.1109/ACSSC.1994.471533, pg 653-656

Ueda, T. ; Tanaka, S. ; Saha, D. ; Roy, S. ; Bandyopadhyay, S. , An efficient MAC protocol with direction finding scheme in wireless ad hoc network using directional antenna, Proceedings on Radio and Wireless Conference, 2003. RAWCON '03. DOI: 10.1109/RAWCON.2003.1227935, pg 181-184

Xueli Sheng ; Xizhong Bao ; Fangfang Luo, Research on Vector Sensor Direction Finding Technology in Intensive Coherent Interference, Second International Workshop on Computer Science and Engineering, 2009. WCSE '09. Vol 2, DOI: 10.1109/WCSE.2009.832. pg 367-370

Zimmermann, L. ; Goetz, A. ; Fischer, G. ; Weigel, R., GSM mobile phone localization using time difference of arrival and angle of arrival estimation, 2012 9th International Multi-Conference on Systems, Signals and Devices (SSD), DOI: 10.1109/SSD.2012.6197970, pg 1 - 7