Phased Array Antennas and their Localisation Capability

Abonyi D.O
Enugu State University of Science and Technology
DOAbonyi1@sheffield.ac.uk

Offor K. J
Chukwuemeka Odumegwu Ojukwu University
ken.offor@ansu.edu.ng

Abstract

Localisation is an unavoidable practise in the world because naturally man keeps searching for one thing or the other in his daily life. With the growth in technology, these naturally occurring search is advancing rapidly to accommodate more search objects like aircrafts, mobile phones, moving vehicles, tags in shops etc. Localization is therefore the process of trying to electronically locate the position of objects in space. These electronic search has been implemented in different ways like in Radio Frequency Identification (RFID), RADAR, GPS, Remote sensing and also in our popular cellular mobile communication where BTS must locate the MS for communication to occur. This paper x-rays the theory of phased array antennas and with simulation of uniform linear antenna array radiation patterns, showed how localisation can be achieved using RSS algorithm. Pre-determined patterns were obtained by simulation of 2-element antennas in space. The two antenna array system was located at the centre of an x-y-plane and ten randomly scattered points were displayed randomly within the plane to represent the radio units which are at this point of this research stationary. Applying the theory which says that a directional antenna will have its maximum transmission or reception in the direction of its maximum gain, it was shown that the pattern with highest received signal strength for a particular node will have that node located at its region.

Key words: Localisation, Phased array antennas, Received signal strength (RSS), Antenna pattern

INTRODUCTION

Searching is an everyday affair, so long as man lives, search will continue to exist. In our everyday life, something is always being being searched. Technology has tried tremendously to make this search a lot easier and more sophisticated and interesting. Serious technological applied search can be traced to the invention of RADAR- Radio Detection and Ranging system which was a helpful tool to England during the world war 11. They used a defence Radar which was based on keeping the volume of sky under surveillance literally 'floodlit' with RF energy, the back scattered echoes from all aircraft within this volume are received at the ground station by a set of crossed-dipole connected to a low-noise, high-gain receiver and displayed as a Y-deflection along the time base of a CRT. The aircraft range is a precise measurement of the time between pulse transmission and the echo reception and the bearing is a measure of the ratio of 'echo' strengths of the X- and Y-components of the crossed-dipoles. Researchers have worked hard in this area for an improved target detection and localisation in general. An improved phased array radar has been developed (Tei-Wei, Yung-Sheng, Chin-Fu, & Cheng, 2005). A MIMO radar has also been developed (Hassanien & Vorobyov, 2010a, 2010b) and a combination of both Phased array and MIMO was proposed (Guang & Abeysekera, 2013) and proved to have the best performance (Hassanien & Vorobyov, 2010b). Radio Frequency Identification (RFID) is another area that has drawn a lot of interest in recent times, the fundamental of this technology is that a spectrum of radio frequency is used to transfer the identification information between two communication devices: RFID tags and RFID readers (Po, Wenyan, Moniri, & Chibelushi, 2013). In other to save memory space in the tag, a network RFID has been developed which tries to remove data from the tag and manipulates the data on the network (Donggeon, Seongyun, Howon, & Namje, 2010). Phased array RFID has been widely applied in areas like retail item management, access control system, electronic toll collection, and etc (Tzyh-Ghuang, Chao-Wei, Ren-Ching, & Cheng-Fa, 2008). Phased arrays has been used in Global positioning systems (GPS) for more precise measurements and to provide anti-jamming effect (Kai, Ling, Zhongxiang, & Boyu, 2006).

Localisation can be classified into range-based or range-free localisation. Range-based localizations achieve high location accuracy by using specific hardware or using absolute received signal strength indicator (RSSI) values, whereas range-free approaches obtain location estimates with lower accuracy. Because of the hardware and energy constraints in sensor networks, RSSI offers a convenient method to find the position of sensor nodes (Mistry & Mistry, 2015).

THEORY OF PHASED ARRAY ANTENNA

Phased array antenna is a collection of two or more antenna elements in an array with the relative phases of the respective signals feeding the elements or being received by the elements set in such a way that the radiation pattern of the array is reinforced in a wanted direction and suppressed in an unwanted direction. The antenna elements can be dipoles, helices, spirals, micro-strip antennas, open-ended waveguides, slotted waveguides etc. Antenna elements are arranged in different configurations to achieve a desired radiation pattern. These configurations can be linear if arranged in a straight line, planar if arranged in a 2D plane which can be circular, square or rectangular aperture and then conformal if arranged in a non-planar surface, for example if arranged to conform to an existing surface of different shapes. Phased array antennas has been applied for ground based multi-function radar for military use, airborne radar for surveillance (RBE2), space borne SAR and communications for remote sensing and also in radio astronomy.

Uniform Linear Array (ULA)

Uniform Linear array consists of identical antenna elements that are equally spaced, excited with uniform current with progressive phase shift and arranged in a line called the axis of the array. The array beam is formed by coherent addition of the individual radiation in space. Figure 1 illustrates a ULA.

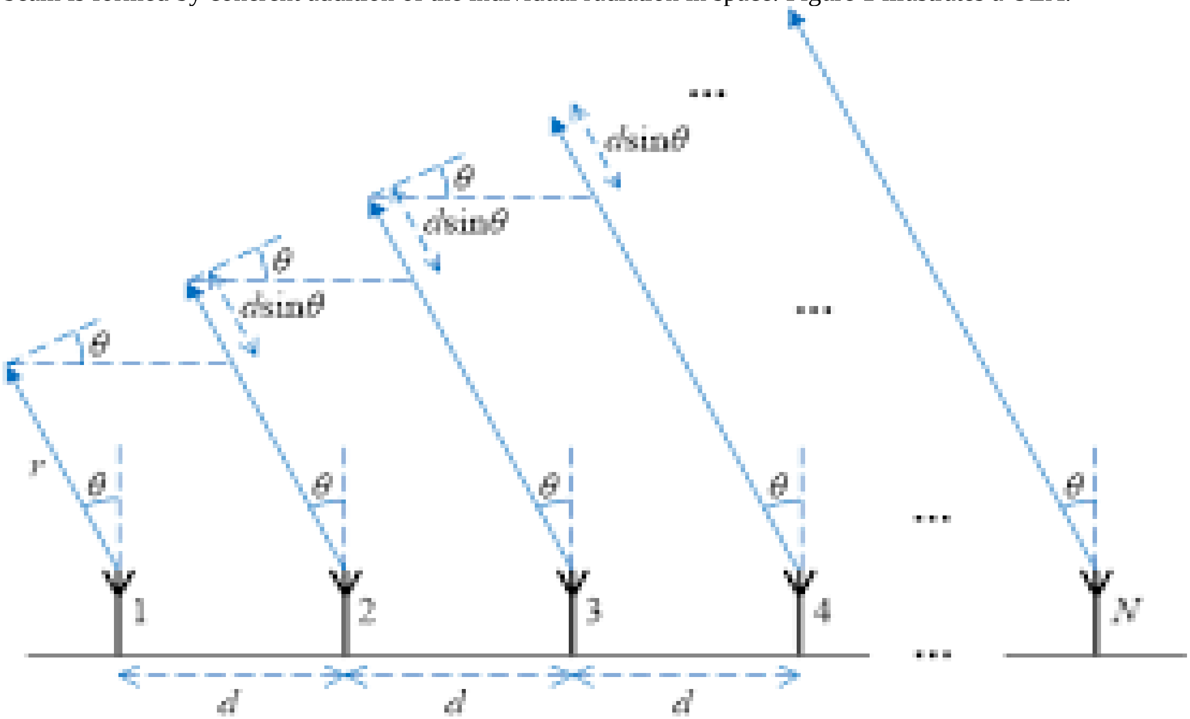

Figure 1: Uniform phases array antenna structure

Mathematical Background

From figure 1, assuming the output from ith antenna at a specific time is x_i, and this output is weighted by w_i, the Array output, S is given by;

$$S_{(\theta)} = \sum_{i=1}^{n} w_i \, x_i \qquad 1$$

A signal is described by its amplitude and phase, therefore the signal received or transmitted by each antenna at a specific time is given by;

$$X(z,t) = x(t)e^{-jkZ} \qquad 2$$

where $z \text{ is a position vector}$

$k \text{ is the wave vector which describes the phase variation of the plane wave.}$

$k = (k_x, k_x, k_x) = {}^{2\pi}/_{\lambda} (\sin\theta\cos\phi, \sin\theta\sin\phi, \cos\theta)$ 3

The wave vector is a property of the plane wave and will always be equal to the magnitude for a plane wave. Therefore;

$k = {}^{2\pi}/_{\lambda} \left({}^{radians}/_{sec.}\right)$ 4

Writing the normalised field pattern for each antenna as a function of k, array output of equation I can be written as;

$S_{(\theta)} = \sum_{i=1}^{n} w_i \, x(t) e^{-jkZ_i} F(k)$ 6

For identical elements;

$S_{(\theta)} = x(t)F(k)[\sum_{i=1}^{n} w_i \, e^{-jkZ_i}]$ 7

where; Z_i $\text{is the position of the ith element in the array}$

The term in square bracket is known as the Array Factor. Equation 5 is the pattern multiplication equation which says that the array output is given by the received signal multiplied by the element factor and the Array Factor. This is valid for arrays with identical elements and oriented in the same direction.

For a one-dimensional array with elements arranged in z-axis, considering equation (3)

$Array\ Factor, AF = \sum_{i=1}^{n} w_i \, e^{-jkZ_i\cos\theta}$ 8

AF is a function of only the elevation angle for a one-dimensional array and so can only filter signal based on their polar angle, θ but cannot differentiate arriving signal based on their azimuth angle, ϕ. Array Factor can be used to examine the effect of an array on the received signal as a function of the angle of arrival. This is a plot of the radiation pattern.

Beam Steering

The simplest way of steering a beam is by applying a linear phase taper to the weight. This can be achieved my applying a phase shifter to enforce a phase delay on the signals arriving on the different elements of the antenna. In other to steer the array to a direction θ', w_n will be;

$w_i = e^{jkZ_i\cos\theta'}$ 9

Substituting equation (9) into (8);

$AF = \sum_{i=1}^{n} e^{-jkZ_i\cos\theta} \, e^{jkZ_i\cos\theta'}$ 10

In more compact form;

$AF = \sum_{i=1}^{n} e^{jkZ_i(\cos\theta' - \cos\theta)}$ 11

For a ULA, with distance d between adjacent antennas. The position of ith antenna for i=1,2………n will be;

$Z_i = d(i-1) - (\frac{d(n-1)}{2})$ 12

Considering a progressive phase values, β for each element, equation 10 becomes;

$S_{(\theta)} = \sum_{i=1}^{n} e^{j(kZ_i cos\theta' + \beta)} * e^{-jkZ_i cos\theta}$ 13

Where; $\theta \text{ is the angle of arraival of plane wave}$

$\theta' \text{ is the focusing or steering angle}$

$Z_i \text{ is the position of ith element in the array}$

$\beta \text{ is the phase of each element}$

$k \text{ is the wave constance given by } 2\pi/\lambda$

In this paper, a broadside array is considered and so $\theta' = 90\ degrees$ where array axis is along z-axis of a spherical coordinate system.

Simulation of radiation pattern of 2-element uniform linear antenna array (ULA) for selected phases.

Matlab code was used to produce different patterns for different phases of antenna 1 and antenna 2 after which the following phases of table 1 were selected. Cartesian plots achieved by individual phases and showing a coverage over 360 degrees from these patterns are shown in Figure 2.

Table 1: Selected Phases

Phase of Antenna 1, β_1	Phase of Antenna 2, β_2	Patterns
0	0	P1
0	120	P2
120	0	P3
0	180	P4

SIMULATION RESULTS

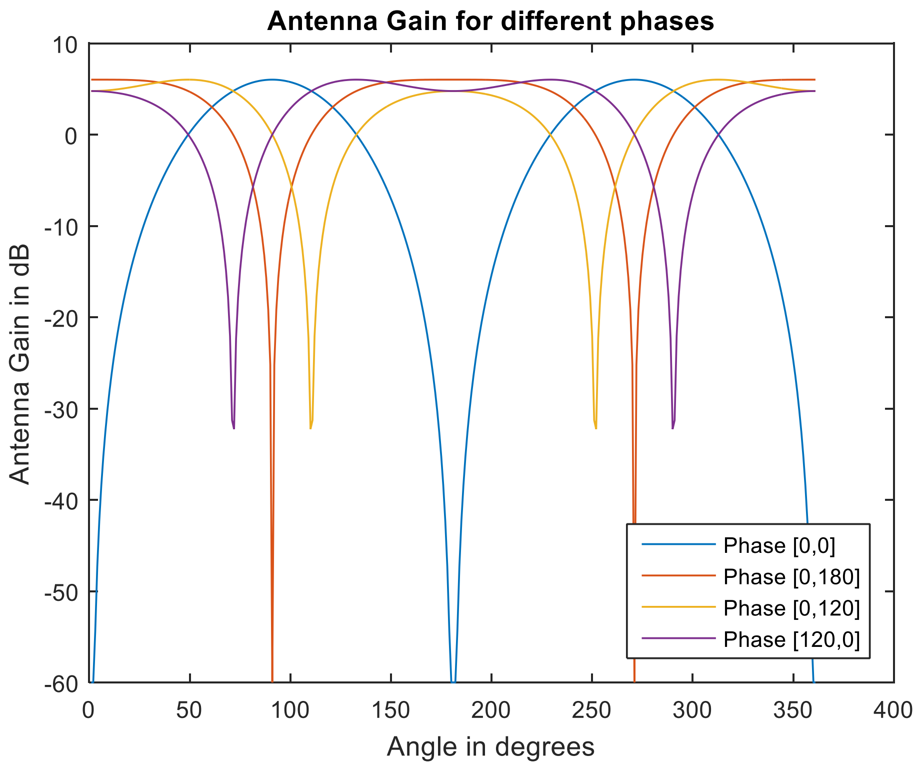

Figure 2: 360 degrees coverage of selected phases

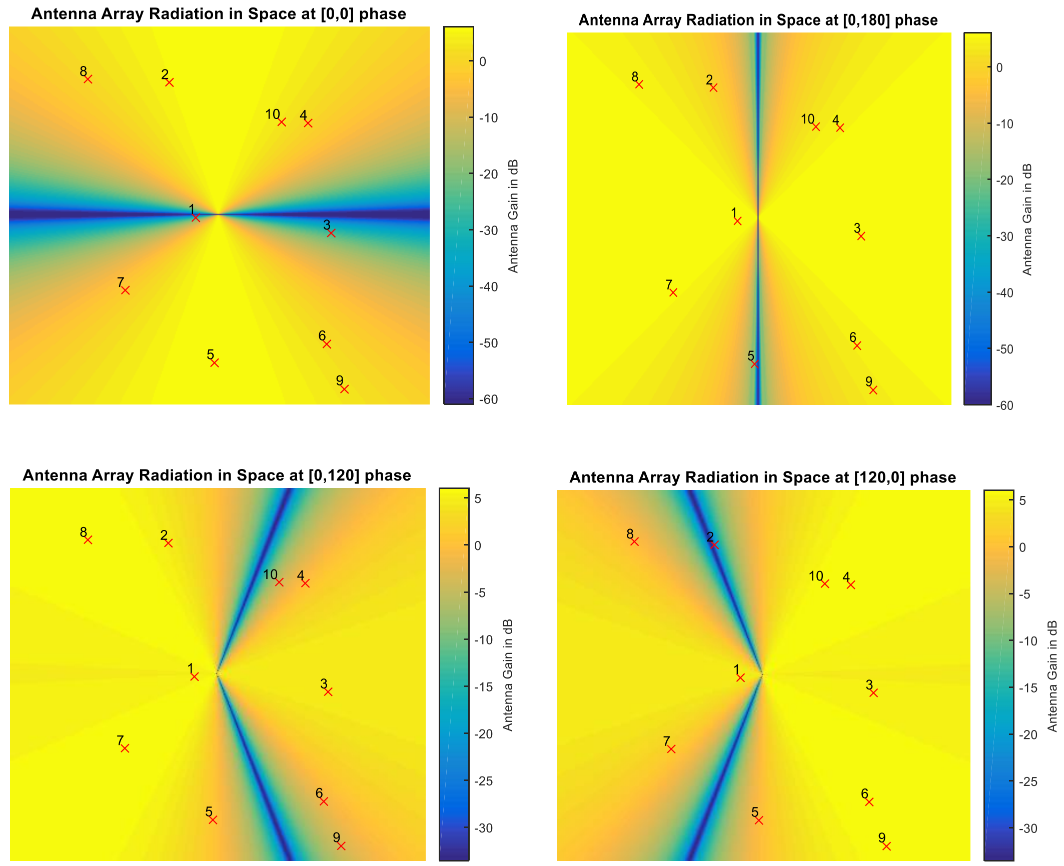

Figure 3: Antenna array radiation pattern in space for P1, P2, P3, and P4 respectively

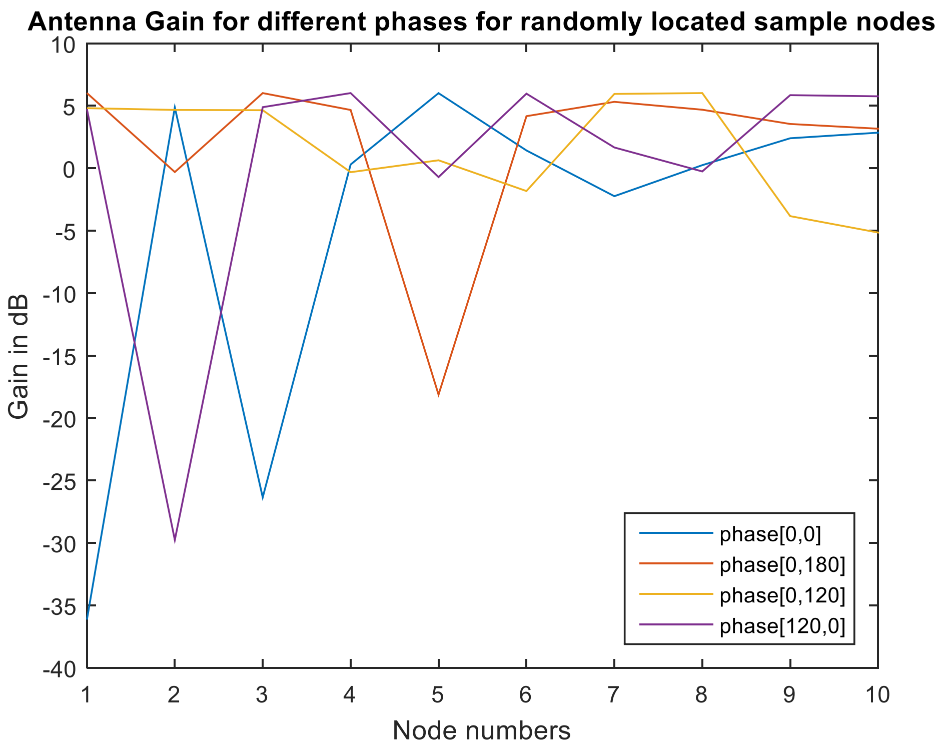

Figure 4: Pattern comparison for ten sample nodes

DISCUSSION

Following the fact that the pattern with highest gain will receive highest RSS from a radio unit in front of the pattern, the following can be derived from the results of figures 2, 3 and 4 above.

- Node 1: P2 will receive the highest RSS from node 1 meaning that node 1 is located on the region of pattern 2
- Node 2: P1 will receive highest RSS at this point meaning node 2 is located in pattern 1 region.
- Node 3: P2 will receive highest RSS. Therefore this node must be located in the region of pattern 2
- Node 4: P4 will receive highest RSS. Therefore this node must be located in the region of pattern 4
- Node 5: P1 will receive highest RSS. Therefore this node must be located in the region of pattern 1
- Node 6: P4 will receive highest RSS. Therefore this node must be located in the region of pattern 4
- Node 7: P3 will receive highest RSS. Therefore this node must be located in the region of pattern 3
- Node 8: P3 will receive highest RSS. Therefore this node must be located in the region of pattern 3
- Node 9: P4 will receive highest RSS. Therefore this node must be located in the region of pattern 4
- Node 10: P4 will receive highest RSS. Therefore this node must be located in the region of pattern 4

CONCLUSION

This is an on-going research and in this paper we have demonstrated a novel and simple approach to localisation using 2-element phased array antennas. It was shown that using pre-determined array radiation patterns, the angle of arrival (AOA) of the signal from a node can be determined by considering the pattern with highest RSS as compared with all other patterns and a conclusion can be drawn that the node is located in the region of maximum radiation of that pattern. This can be applied to direction finding system design. It can be a very useful tool for mobile network planners to determine regions of high mobile users for deployment of smaller cells.

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