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Enhancing the Performance of Localization System for Radio Frequency Transmitters Based on DOA and Triangulation algorithms

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Abstract - *In wireless communication channels, many challenges oblige the presence of radio monitoring systems, such as the Direction Finding (DF) system and localization system of Radio Frequency (RF) transmitters. These systems identify the directions and distances depend on the set of algorithms to determine the actual transmitter position. Therefore, it has critical applications such as communication security and military applications. It consists of a central processor connecting to a network of passive sensors called the DF nodes distributed in the scanning area. The main principle of DF and localization systems are based on estimation techniques at each DF node, which senses the distances and directions with specific instructions to perform DF and localization functions. This paper presents a high-resolution DF and localization system simulation, which can effectively monitor the signals being emitted by the RF transmitters and calculate the number of targets. This simulation consists of the implementation of DF algorithms in each DF node, which is connected to other nodes in single-source environments with fixed target positions, and then applies a triangulation algorithm to obtain the RF transmitter location. The simulation results were performed for many cases to enhance the accuracy of DF and localization systems. The results show UCA-Root-MUSIC has robust estimation that can be obtained with a sufficiently small error.*

Keywords — *MVDR, ROOT-MUSIC, ROOT-WSF.*

I. INTRODUCTION

Wireless communications have essential and sensitive applications in many fields of life and specifically in the era of a technology revolution. Many devices connect on the wireless channel, such as computers, mobile phones, and fixed wireless devices are video and teleconferencing systems [1]. There are requirements for reliable services with more security and better quality as the connected devices increase [1]. Therefore, wireless channels must be kept in better status without any jamming process, interferences, or illegal RF emitters. These are done by DF and localization systems. One of the essential advantages of DF and localization system is spectrum monitoring, which forces the RF transmitter obedience to international radio traffic laws, as violations can be monitored and tracked in time [2]. Spectrum monitoring allows wireless traffic to monitor radio stations, police devices, radio hams, and air traffic, which appear on the spectrum simultaneously with various frequency bands and must not cause mutual interference [2].

Moreover, it has an advantage in combating organized crime or risks that threaten national security. So that, this system considers as the most significant and influential facility for maintaining peace [1], [2]. In the localization system, the target location information can be estimated based on the DF algorithm and the position DF node, represented as the geometric representation. This representation describes the scanning space with its geometric shape through coordinate points based on a Cartesian coordinate reference system [3]. The scanning space model consists of a fixed representation representing a particular space with coordinates (x, y, z) called the location-scanning area. Geometrically, the location-scanning area is configured from different geometric shapes, including 2D or 3D shapes [4]. The form may be developed to become a more complex shape based on the applications [4]. Every scanning space is represented using coordinates specified and then formatted with a particular form to achieve geometric scanning space [3]. The coordinate representation has a forced relationship with the geometric shape of a scanning space. DF node positions in the DF and localization system can be located depending on the basic principle of the intersection of various lines with the correct geometric configuration to estimate the location of the RF source [4]. There are different DF techniques to estimate the location of the RF transmitter, which are received signal strength (RSS), the direction of arrival (DOA), time of arrival (TOA), and time difference of arrival (TDOA). RF localization system uses these techniques with the scanning space's geometry to estimate transmitters' locations by using the intersection lines, angles, and mathematical relations such as triangulation, multilateration, and hyperbolic [2].

DF and localization systems utilized direction of arrival (DOA) algorithm estimation that has the primary function to estimate the direction of the signal [3], [5]. DF system collects parameters of the received signal to determine where the signal is coming from [3], [5]. Therefore, it is used in the military fields, public safety, law enforcement, and geological representation of signals distribution. Practically, the DOA algorithm is based on digital processing techniques with the model of an antenna array that may be constant or rotating at a particular speed [2], [3]. This array consists of a set of spatial antennas that sense the incoming signals. Therefore, a signal emitter appears on the antenna array with instantaneous variation in the parameters of the incoming signals to estimate the DOA [5], [6]. A fixing antenna array is used instead of one rotating antenna element because it is neither desirable nor practical. The antenna array is arranged with a specific geometry that consists of several elements such as dipole, monopole, and crossed loops. They have been electronically sampled using electronic switches that are known as cyclic scanning [8]. To obtain correct DOA estimations, the spacing between the individual antenna elements must be less than half the operating wavelength. Spacing elements should be changed according to the incoming signal wavelength [8]. All DF nodes require a DF computing process in the localization process and send data for beginning the computational location estimation. The optimal location estimation can be achieved without any location error of the DF nodes and any DF error. Therefore, the system achieves good performance with a perfect measure [7]. However, when an error exists, the system model estimates an incorrect location that differs from the actual transmitter location. The computational effort can be achieved by improving the estimation algorithms in each node and also require the minimum number of DF nodes [7]. A reduction in the computational effort could also be obtained by considering the estimation results of two DF nodes by assuming that RF transmitter at a fixed location [7].

This paper will present the DF and localization system simulation using MATLAB based on DOA algorithms and triangulation in both single and multiple-source environments using a set of connected passive DF nodes to show how the enchantment can be proved.

The paper is organized as follows: Section II presents an overview of DF and localization system, and DF algorithms, and triangulation process. Next, Section III deals with obtained results from a simulation of DF and localization system with various techniques. Finally, the last Section IV, consists of the conclusions of our research.

II. RESEARCH METHOD

In this section, DF and localization system are presented with all algorithms, which are used in the Matlab simulation. These algorithms are Capon's Minimum Variance Distortion less Response (MVDR), Root Multiple Signal Classification (Root-MUSIC), Estimation of Signal Parameters via Rotational Invariance Technique (ESPRIT), and Root Weighted Subspace Fitting (Root-WSF). All these algorithms are used to estimate the accurate DOA in each, and then the triangulation process is used to estimate the location of the RF transmitter.

A. DF and Localization System Architecture

DF and localization system of RF transmitters is defined as the set of operations, computations, and algorithm steps to estimate the desired location of a specific transmitter. This system configures from a set of passive sensor nodes that lay in the scanning area. These nodes have coordinates that have been known for DF and localization system. RF nodes are distributed with a specific technology to prove the correct estimation [10], [11]. DF and localization system is portable that can be available any time, everywhere, outside in the street, on the buildings, etc. Therefore, this system is important to check the spectrum, specify the locations of RF transmitters, assist in keeping public safety, and efficiently monitor the communication logistics [10]. This proposed system is to define the signal direction, estimate the location, and track the RF transmitters, which prove an essential advantage for future RF mappings, such as wireless sensor networks and mobile communication systems. This system can monitor directional power radiation/reception, dynamic spectrum access, automatic transmitter localization, and tracking [10]. Additionally, the system can frequency sensing enables beamforming for rejecting frequency hopping, DOA estimation, suppressing jamming, and interference to provide safety communication links [3]. Fig. 1 shows the system architecture that consists of a set of RF nodes. These nodes have array elements in which collect signals, and then it is processed with signal processing techniques to estimate where the signals are coming from. Each RF node enables DF estimation for the localization processor to specify the RF transmitter coordinates and computing the distances to represent the obtained coordinates on the map [3].

RF nodes are important components of the DF and localization Intelligence system that are known as passive sensors. It can estimate RF transmitter signal parameters such as DOA that obtain antenna arrays [10]. DOA estimation algorithm is used in each node with the defined locations of DF nodes; the location of the RF transmitter can be estimated through localization techniques [9]. Generally, the localization processor periodically collates the data of RF nodes and then applies a triangulation process to estimate the transmitter location. The proposed system studies are based on an accurate DOA algorithm and triangulation process to improve DF and localization accuracy [7].

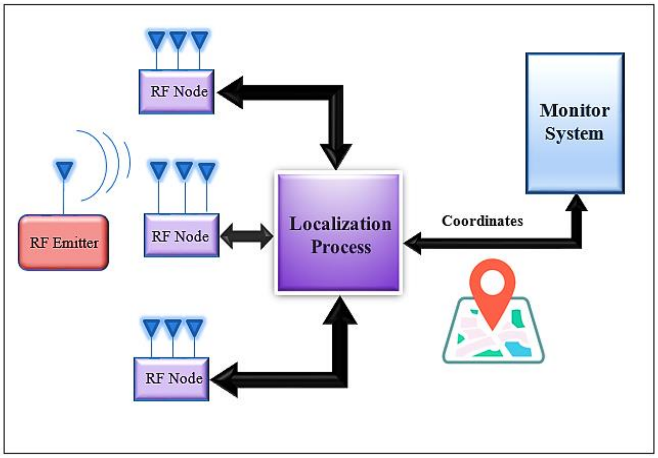

Fig. 1 Block Diagram of DF and Localization System

B. Overview of DOA algorithms

In recent years, many investigations are accomplished attached to DOA estimations that study using different methods, various signals, cases, conditions, and geometric shapes of the antenna array. As shown in Fig.2, the DOA estimation term is known when signals are combined from antenna array elements and processed to understand where the signals come from. The performance of DOA is mainly dependent and considerably affected by the array topology [1],[4]. According to researches, DOA estimation methods are classified into two categories. The first group depends on calculating the spatial spectrum for the incoming signals and determining the DOA methods by specifying the spectrum peaks, which are called spectral-based algorithms. It is also known as the conventional method, which has a powerful resolution because it is based on the array aperture's physical size, such as MVDR [3]. The second group depends on the Eigen decomposition that directly estimates DOA methods without computing the spectrum. Therefore, it is known as parametric arrays processing techniques such as Root-Music and Root-WSF. In these techniques, when the performance increases, it becomes higher complexity and more computations with higher accuracy and resolution than the first group [19].

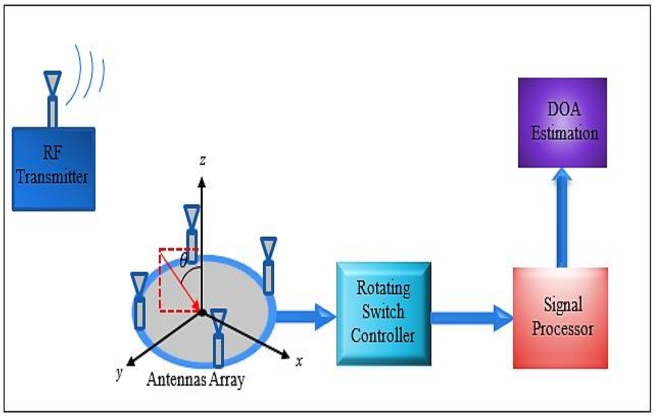

Fig. 2 Block Diagram of DOA Estimation

***a) MVDR*:** is standard for Capon's minimum variance distortionless response, which has a technique similar to the Beamscan approach by computing the received power of the incoming signals in all available directions. In this algorithm, the power with the angle is estimated by limiting the beamformer gain of proper direction to be 1 and use the remaining freedom degrees to reduce the collective output power of incoming signals arriving from all available directions.

$$P_{\mathrm{MVDR}}(\theta) = \frac{1}{\mathrm{a}^{H}(\theta)\mathrm{R}^{-1}\mathrm{a}(\theta)} \tag{1}$$

The disadvantage of the MVDR algorithm is the need to calculate the inverse matrix that may fail if the significantly correlated signals are coming. However, this method gives a high resolution in the DOA estimation than the Beamscan method [8],[13].

b) Root-MUSIC: has developed by adding several modifications and many improvements to become more accurate and less the calculation complexity. Therefore, it is called Root-Music, because it utilizes Polynomial-rooting techniques and polynomial parameterization to estimate DOA, which is developed by Barbell [3]. In addition, Root-Music uses the roots and properties of the signal Eigenvector inside the unit circle to estimate the DOA of the sources and know the rational spectrum function with enhanced resolution possibility. In comparison cases, the root music is selected over many DOA techniques because it is immediately derived from MUSIC techniques, which provides a higher performance-complexity tradeoff. However, it is used only for a uniform spaced linear array [3], [17].

Root- MUSIC can be expressed in the following:

$$\theta_l = \arcsin\left(\frac{\lambda \cdot \arg(z_l)}{2\pi d}\right) \tag{2}$$

Where θ_ℓ is the estimated angle and d is the separation between sub-array elements.

c) Root-WSF: is a Root-weighted subspace-fitting algorithm that is another mothed for DOA estimation. It employs for detecting coherent signals specifically in a multipath environment. It is one of the most mothed to use, especially where the multipath environment is typical, and some methods fail in this case. However, this method is iterative to get its accuracy and recognize a coherent signal source so that it demands more computational complexity result in a longer computational time. Nevertheless, it provides a higher angular resolution and immunity to multipath attenuation [3].

$$f(\theta) = \mathrm{Tr}\left(P^{\perp}_{a(\theta)} \hat{V}_S W_{MODE} \hat{V}_S^H\right) \quad (3)$$

W_{MODE} is related to the asymptotic-optimum weight matrix, ⌢ and VS is eigenvectors in a diagonal noise matrix. $P^{\perp}_{a(\theta)}$ shows the orthogonal projection matrix of a steering matrix of the array.

C. Triangulation Process

The triangulation process is used for the DOA Techniques to compute the RF transmitter's location, which is based on vector ranging. This process requires at least two RF nodes to estimate the DOA of the received RF signals [11]. The triangulation process means a pair of vectors form a single angle at a point when they intersect with each other. Therefore, the RF transmitter represents the intersection of lines drawn from RF nodes to the RF transmitter, as shown in Fig.4. Thus, the DOA estimation in each RF node and other necessary information can compute the RF transmitter's location.

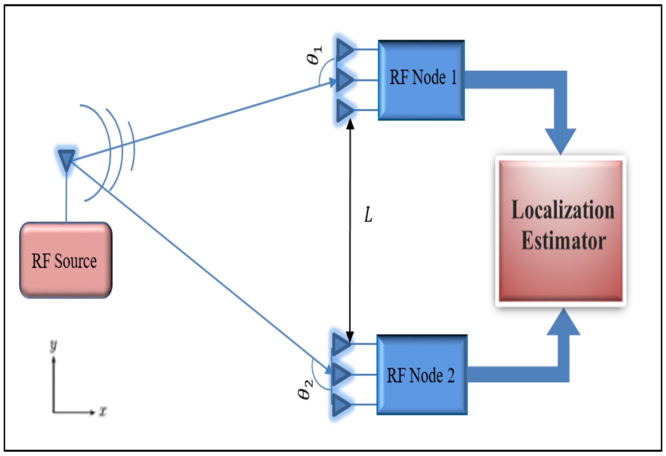

Fig. 3 Block diagram of the triangulation process

One of the RF nodes with known coordinates must be used as a reference node to other remaining nodes to obtain accurate computation of the required information in this technique [9]. Therefore, the triangulation process depends on simple trigonometric formulas. For example, assume that the RF nodes are located at the 2-D coordinates with L distance between two RF nodes and the unknown source location (x,y). Then, from the RF nodes, the two estimated DOA (θ1, θ2) could be used to estimate the (x,y) coordinates of the RF transmitter in (4) and (5) [9].

$$x = \frac{L}{\tan\theta_1 + tan\theta_2} \quad (4)$$

Then for y:

$$y = xtan\theta_1 \quad (5)$$

RF transmitter coordinates ($Xest$, $Yest$) is calculated by the centroid algorithm refers to equation (4) [1].

$$(X_{est}Y_{est}) = \left(\frac{X_1+X_2+\cdots+X_N}{N}, \frac{Y_1+Y_2+\cdots+Y_N}{N}\right) \quad (6)$$

D. Overview of DF Array Geometry

In wireless communication, researchers had worked hard themselves as seriously exploring the multiple antenna scope to obtain the best performance, and thus they reached the smart antenna concept. Smart antenna systems are swiftly appearing as essential techniques that prove a perfect function to improve the overall DF system performance. By signal processing techniques, a smart antenna can estimate accurate DOA, immunity to noise and interference, improve the DF system behavior, and minimize overall infrastructure costs [15],[17]. DOA algorithms are able to the perfect performance with related array geometries. This is achieved by the best specifications of array geometries [15]. Multiple antennas are adequate for the DF systems since they able the DOA estimation of numerous almost impossible signals with a single antenna. This paper introduces the most common antenna array geometries in the simulation of DF and localization systems. This simulation demonstrates the arranging of elements through various parameters, such as several elements and spacing of inter-element based on the signal's wavelength.

Additionally, it deals with the analysis of the characteristics of array geometries such as radiation patterns and the time delay among elements that are considered as essential impacts of the DOA performance. It has the most basic common types of antenna array geometries: uniform linear arrays (ULA) and uniform circular arrays (UCA). These types are comprehensively studied with various algorithms that have been considered to estimate the (DOAs) of signals arriving at the antenna array. Each type express in the following:

a) ULA: is a set of antenna elements arranging as a straight line located on the axis. Sub-element has a special sub-distance with other sub-elements based on the wavelength of the received signal. The first sub-element is situated at the origin position. It is considered a reference element to the other sub-element arranged beside it [8],[22] ULA is a conventional type of antenna array geometry that is regarded as the basic configuration of the antenna arrays. Furthermore, it is an essential object to study how much effect ULA geometry has on the performance of DF and localization systems because this geometry has a simple structure and widely use. Recently, some super-resolution DOA algorithms are configured only with ULA. However, ULA has drawbacks, such as it can estimate angles only in the range from 0 ° to 180 ° and receive signals with one-dimensional angular only [22]. As shown in Fig. 1, the array elements are configured in the x-axis. The received signal collects the antenna elements from the reference element to the last element [14]. ULA accumulates the incoming signals from a direction of angle related to the broadside of the array.

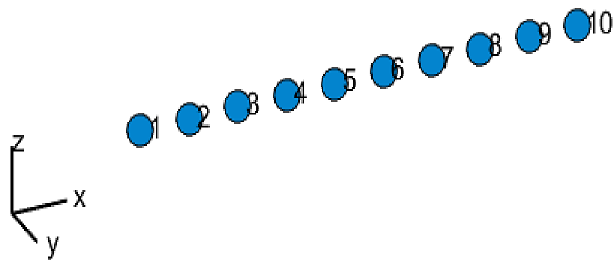

Fig. 4. ULA configuration

b) UCA: is a set of antenna elements configured as a circle form located on the y-x axis. Sub-element has a certain distance to other remaining sub-elements based on the wavelength of the received signal. The first sub-element is located at a distance from the original position, representing a radius and becoming a reference element to the other sub-elements arranged beside it [8], [22]. Fig. 5 shows UCA configures a circle in the x-y plane. This array is profusely used due to its good performance. It deals with two dimensions state and can a constant DOA estimation in the range from 0 ° to 360 ° to estimate the two-dimensional angular of RF transmitter. UCA requires a large number of array elements to improve performance. However, the calculation amount is more, and structures become more complex [8]. Surely, UCA is the most popular configuration of arrays in studies due to its eclectic specifications.

Furthermore, UCA isotropic along the z-axis, implying that the azimuth cannot affect DOA estimation performance. Although UCA is a complex configuration, there is a possibility to enhance this configuration by the insertion of two elements, upper and lower. The circle center enables another configuration called a spherical array [8].

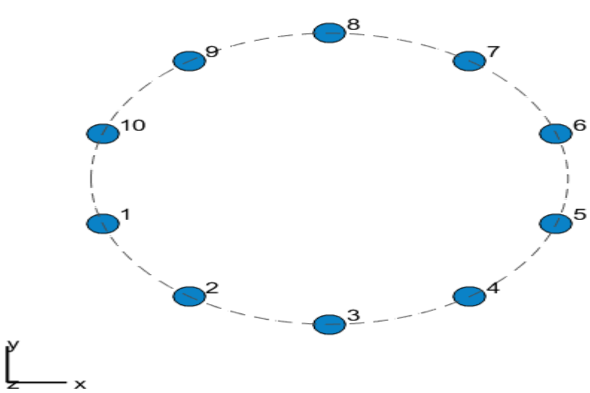

Fig. 5. UCA configuration

III. RESULTS AND DISCUSSIONS

This section presents simulations of DF and localization systems to prove the enhancement where can be made. The simulation parameters were implemented: the scanning area 2000m x 2000m is formed as the square ship with the many RF sensor nodes. The position of all the DF nodes was put in the area with the uniform distribution in the specific configuration to provide the better performance of the system. ULA and UCA were considered in each RF node with various elements and $\lambda/2$ the sub- spacing of each element, where λ is the wavelength of incoming signals. The initial position of the RF node at (0,0) is considered the reference node for the remaining nodes placed in the area. The signals propagated at a frequency 900MHz and the speed of light $3 * 10^8$m/s. The location of the RF transmitter is considered at a static position. The detecting of the RF nodes depends on two DOA algorithms to get the accurate location estimation with minor errors, which can achieve the main goal through the simulation.

A. MVDR

The evaluation of DF and localization system performance based on accuracy estimation under various conditions. This accuracy is measured from the slight difference between the actual location and the estimated location of the RF transmitter. Fig. 6 shows the DF and localization system configuration based on the hybrid DOA algorithms with the distribution of many RF nodes to configure the scanning area to estimate RF transmitter location.

In practice, some errors affect the performance of the DF and localization system performance, such as the error of the DOA and the configuration of the DF nodes. Therefore, this effect is considered in the system design. The centroid concept is used with RF nodes measuring to assure the algorithm's fault minimally. When RF nodes are lay in the scanning area with Gaussian white noise, all nodes are based on a reference node at (0, 0) to estimate its location and determine the required DOA for the RF transmitter. In Fig.6, it is essential to understand that the error moment changes based on the actual location of the transmitter. However, sometimes MVDR fails to estimate the transmitter's location and gives a high distance error. The MVDR algorithm has better performance when the dense distribution of RF nodes is more extensive. With the increase of the RF nodes in the scanning area, and observe RF nodes' impact on the DF and localization system performance. The MVDR algorithm simulation for this system is illustrated in Fig.6.

The first RF node is stationary and considered as a reference node at (0, 0). The location of the 2nd, 3th, and 4th nodes are fixed at (2000, 0), (0, 2000), and (0, -2000), respectively. For the transmitter, signals emitted from (900,1000) coordinates as shown in Fig.6. MVDR estimation was obtained from the first node and second node, respectively. These obtained values with the triangulation process take the transmitter location. The estimated coordinates are at (895, 994).

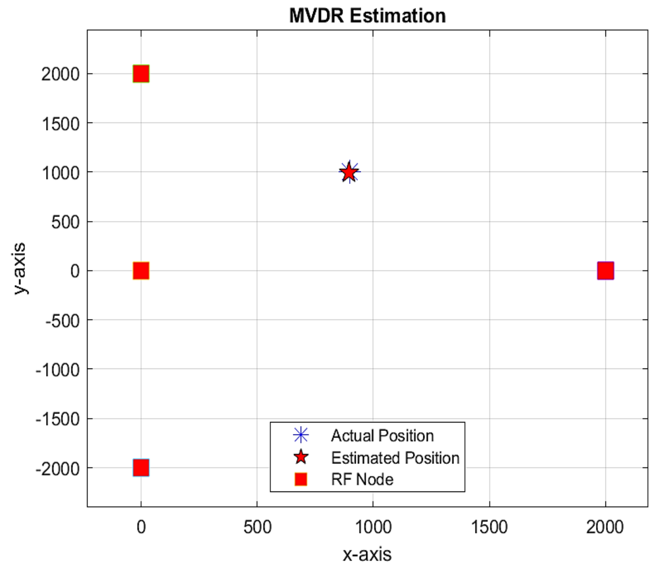

Fig. 6. Frist estimation by ULA-MVDR

The performance of ULA with the MVDR estimation algorithm with two RF nodes and two RF transmitters, where the simulation was implemented with 10 elements of the antenna array. By using ULA, the MVDR algorithm scan all the angles defined in the simulation. As shown in Fig. 7 for all nodes, the graph of power versus the scanned angles consists of a curve for MVDR estimation to show the peak graph of MVDR and configure a general idea of the chart. This chart can be used for data analysis and to estimate the correct DOA. For example, in ULA-MVDR estimation, the graph peaks are shown in Fig. 7. Four power peaks against incident angles distinguished easily due to peaks near 0 dB to lower than -140dB.

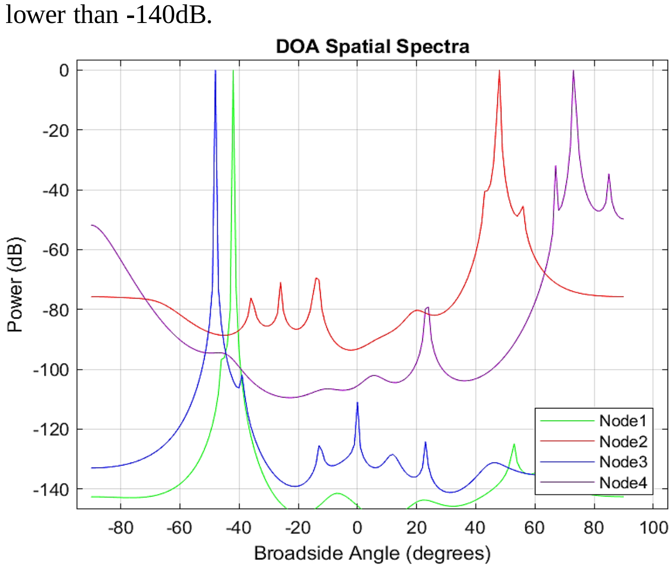

Fig. 7. The spatial spectrum of the first estimation for the four RF nodes

In the second scenario, when transmitter location behind RF nodes, as shown in Fig.8, the transmitter emits signals out of the scanning angle range of ULA. MVDR estimates incorrect incident angles because ULA can scan within 180 degrees, and most RF nodes cannot estimate the DOA of the transmitter. Therefore, Fig. 7 shows the incorrect location obtained from the MVDR algorithm in using ULA.

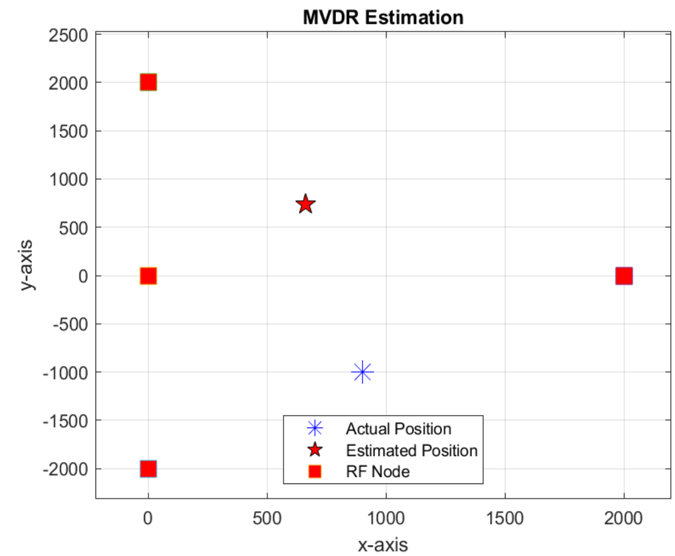

Fig. 8. Second estimation by ULA-MVDR

In Fig.9, the graph of power peaks against the incorrectly estimated angles. There are four power peaks against incident angles, which can be organized directly in the DOA curve. This spatial spectrum shows how RF nodes give incorrect DOA. Therefore, the MVDR algorithm with ULA fails in estimation and provides an incorrect location.

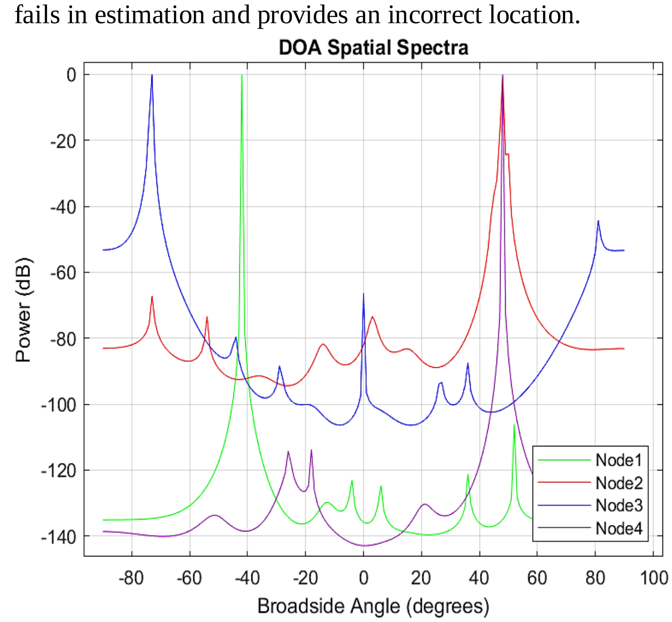

Fig. 9. The spatial spectrum of the second estimation for the four RF nodes

The estimation is enhanced to become high resolution using UCA. It can operate in the scanning angle from 0 ° to 360 ° to estimate the RF source of two-dimensional angular. As shown in Fig.10, MVDR with UCA able RF nodes to estimate DOA with 360 °.

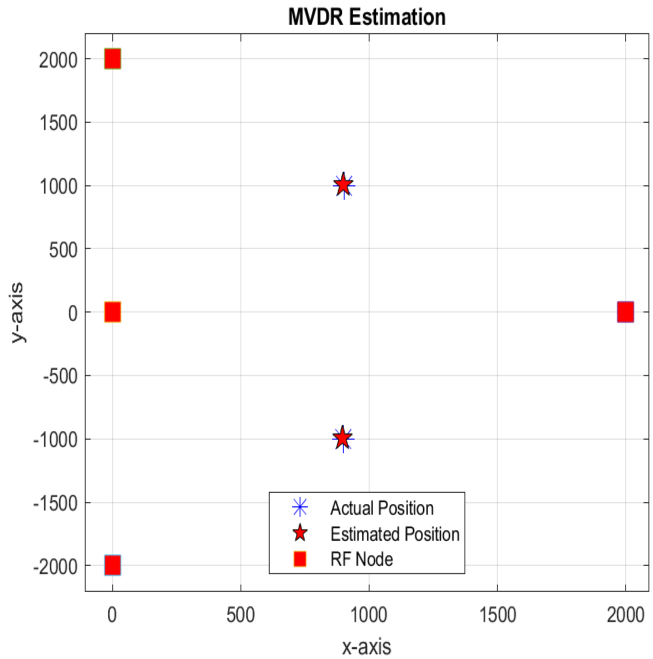

Fig. 10. Third estimation by UCA-MVDR

These results directly tell us that using the MVDR algorithm with UCA for the DF and localization system fits this situation with a minimum number of nodes. As a result, the error of the estimated transmitter location is small.

B. Root-MUSIC

The scenarios considered for this algorithm are illustrated in the figures below, where the RF nodes used are shown in the scanning area with the following arranging. Two scenarios are considered for the transmitter in the scanning area for the Root-MUSIC algorithm. In the first scenario, the transmitter emits signals at (900,1000) as shown in Fig. 11. DOA estimation was obtained from all nodes in the scanning area. In ULA-Root-MUSIC, the high-resolution DOA is obtained as the transmitter emits signals with a scanning range. These values of DOA are with the triangulation process estimates the transmitter coordinates at (896, 995).

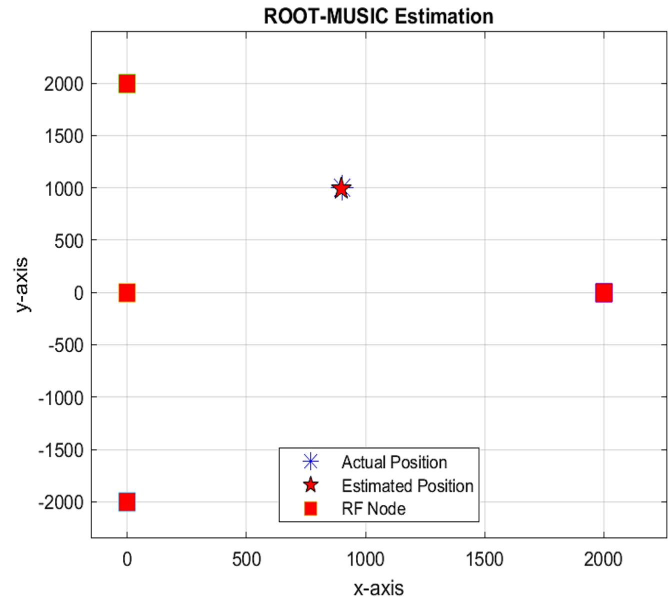

Fig. 11. Frist estimation by ULA-Root-MUSIC

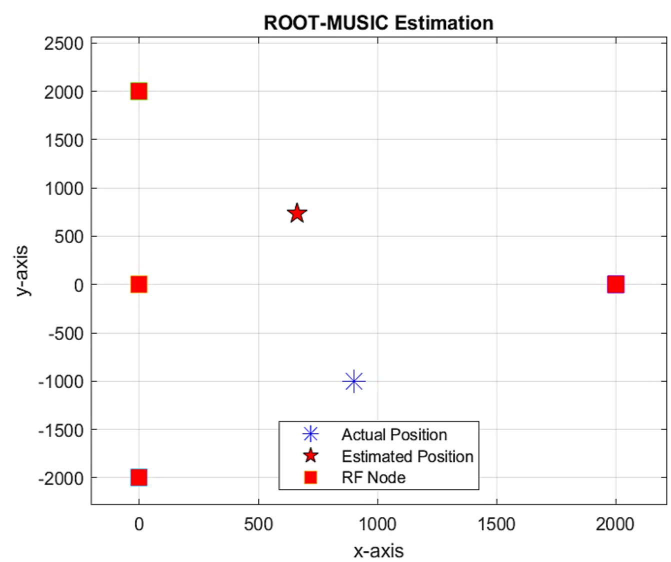

Fig. 12. Second estimation by ULA-Root-MUSIC

In the second scenario, transmitter location at (900,-1000) means behind RF nodes, as shown in Fig.12. Root-MUSIC fails in estimation due to the transmitter emits signals out of the scanning angle range of ULA. It estimates incorrect incident angles because most RF nodes provide incorrect DOA of the transmitter. Therefore, Fig.12 shows Root-MUSIC gives the wrong location obtained with ULA.

As shown in Fig.13, UCA is used to avoid estimation failure with Root-MUSIC. Therefore, the estimation enhanced and became a super-resolution estimation for multiple RF transmitters.

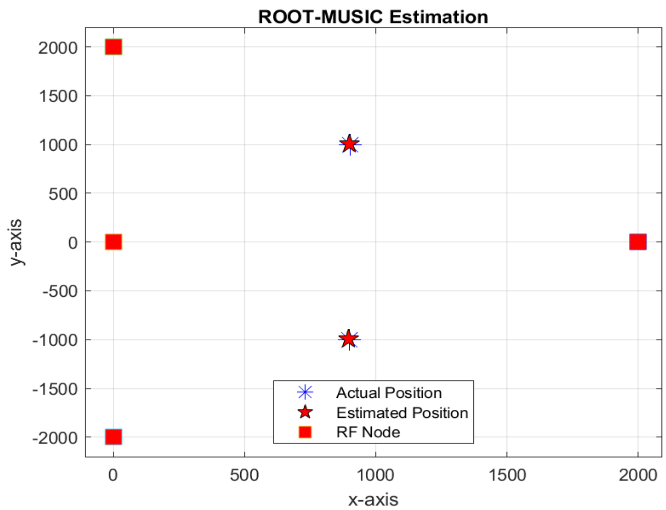

Fig. 13. Third estimation by UCA-Root-MUSIC

The results obtained show the small error between the actual transmitter location and the estimated ROOT-MUSIC algorithm's estimated location compared with the MVDR algorithm. Thus, UCA-Root-MUSIC has perfect performance for DF and localization systems.

C. Root-WSF

In this section, the algorithm is tested in the same scenarios above. In the figures below, where the RF nodes used are configured in the scanning area with simple arranging. Two locations must be estimated for the transmitter in the scanning area. In the Root-WSF algorithm. The first scenario shows the transmitter emits signals at (900,1000) as shown in Fig. 14. DOA estimation was obtained from all nodes in the scanning area. ULA-Root-WSF provides the high-resolution DOA as the transmitter emits signals with a scanning range. These values of DOA are with the triangulation process estimates the transmitter coordinates at (898, 997).

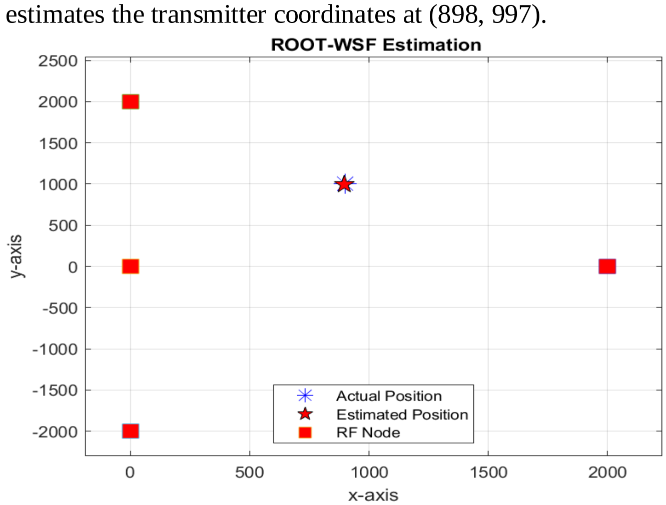

Fig. 14. Frist estimation by ULA-Root-WSF

In this second scenario, as transmitter location at (900,-1000) behind RF nodes, as shown in Fig.15, the transmitter emits signals out of the scanning range of ULA. Root-WSF estimates incorrect DOA due to ULA scan within 180, and most RF nodes cannot estimate the correct DOA of the transmitter. Therefore, Fig. 15 shows the wrong location obtained from the Root-WSF algorithm in using ULA.

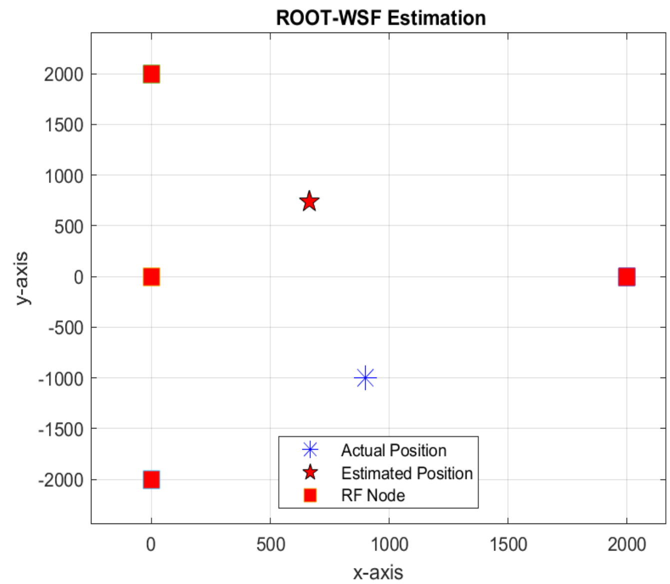

Fig. 15. Frist estimation by ULA-Root-WSF

The results obtained are shown in Fig.14 and Fig.15. As compared all the obtained results, respectively. The ROOT-WSF algorithm gives super-resolution estimation when RF transmitter exists in the scanning range of ULA and fails when RF transmitter exists out of the scanning range of ULA. Additionally, Root-WSF can only operate with ULA. Thus, UCA-ROOT-MUSIC algorithms have better performance for DF and localization systems.

D. The estimation accuracy

This section presents the accuracy of the DF and localization system. The simulation parameters considered are frequency (900MHz), the number of snapshots (2000), and the number of elements (10). Two RF transmitter locations must be estimated by calculating the percentage error for each algorithm with its array configuration, as shown in Table I. The obtained results are shown in Table I. UCA-MVDR and UCA-Root-MUSIC proved a correct estimation compared with others, which fail in estimation. UCA-MVDR demonstrated a good estimation resolution compared with ULA-MVDR, which fail in the estimation. Root-WSF doesn't work with ULA configuration. Therefore, Root-MUSIC provides a suitable performance and has a very high accuracy estimation with unique UCA geometries.

IV. CONCLUSIONS

This paper presents the DF and localization system's enhancement performance that uses multiple connected RF scanning nodes without any mobile human. The system model is based on DOA algorithms and arrays configuration. The DOA data are collected from each RF node; it is then calculated using the triangulation process to identify the transmitter location. Therefore, the RF transmitter location is automatically estimated. The results of DOA estimation are proved to triangulation process, which is based on the intersection point of triangle equations as the transmitter location. The MATLAB simulation is used to verify the accuracy of the DF and localization system. The performance of this system is evaluated in combination with angle detection algorithms such as MVDR, ROOT-MUSIC, and ROOT-WSF. Finally, ROOT-MUSIC with UCA is a suitable technique for the situation with a minimal number of nodes. It can reduce the number of nodes required to be deployed; it is an effective algorithm. When it is easy to get the accurate DOA of the transmitter signal and no error in the node's location, the system calculations are minor. Finally, this proposed system is a compelling performance for the RF transmitter localization with simple principles and measures.

TABLE I. THE ACCURACY OF DOA TECHNIQUES

DOA	First Transmitter (400, 1300)	Second Transmitter (300, -1100)	Parentage Accuracy (%)
ULA-MVDR	(394,1290)	(171,638)	49.1%
UCA-MVDR	(395,1294)	(282,-1091)	97.8%
ULA-Root-MSUIC	(395,1295)	(160,438)	50.3%
UCA-Root-MSUIC	(397,1299)	(299,-1098)	99%
ULA-Root-WSF	(399,1299)	(191,635)	51.4%

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