Wireless sensor network's localization based on multiple signal classification algorithm

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ABSTRACT

Wireless sensor networks (WSNs) are a number of sensitive nodes senses a physical phenomenon at the position of their deployment then sends information to the base station to take appropriate operation. (WSNs) are used in many applications such track military targets, discover fires, study natural phenomena such as earthquakes, humidity, heat, etc. The nodes are spread in large areas and it is difficult to locate them manually because they are published randomly by planes or any other method and since the information received from sensitive nodes is useless without knowing their location in this case a problem resulted in the positioning of the nodes. So it unacceptable to equip each sensor node with global position system (GPS) due to various problems such as raises cost and energy consumption. In this paper explained a non-GPS technique to self-positioning of nodes in (WSNs) by using the multiple signal classification (MUSIC) algorithm to determine the position of the active sensor through estimated the direction of arrival (DOA) of the node signal. Then modified MUSIC algorithm (M-MUSIC) to solve the problem of coherent signal. MATLAB program successfully used to simulate the proposed algorithm.

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1. INTRODUCTION

Wireless sensor networks consist of small sensor nodes that spread in the form of a network and connect wirelessly with a base station that performs the function of sensing or study of a phenomenon that may occur in the spreading environment [1, 2]. WSNs are the result of multiple stages of development during the past decades, since 1950-1990 appeared the first global system of wireless sensors and research in this field continued to develop, in 2001 Intel Labs announced (WSNs) officially. It used in the medical and military fields, studying natural phenomena, tracking things, observing natural phenomena and other uses [3, 4]. There are many challenges and problems are the sensor networks suffers from it such as the environment, conduction and power problems, and storage unit size, but the most important problem is the location of the nodes [5].

Suppose we have a sensors network distributed in a large area or building such as a battlefield or forest characteristic purpose for these networks is sending a data to a base station in a definite position [6, 7]. But this nodes is anonymous location thus generated a big problem which is locating the node in large WSNs where the data sent from this nodes to the base station becomes useless without knowing its location. Although it can be used GPS to set node position but the raise cost of sensor, weak signal in pent environments, not working in indoor environment, line of sight isse and energy consumption prevent using GPS service in large WSNs [8, 9] to solve this problem of sensor location must be designed a non-GPS WSNs localization and self-locate for each sensor node used detection protocols these protocols share many features and most use a special node called a reference node the locations of these nodes are assumed to be known (with manual settings or with GPS service) [10]. This design is known as the central nodes or reference nodes which provide us with location information and give a reference to sensor nodes because the location of sensor nodes depends on the location information from the reference nodes as shown in Figure 1.

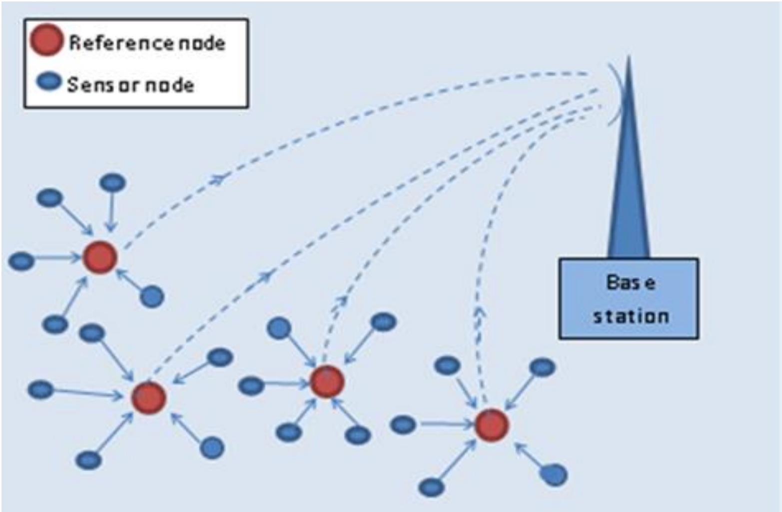

Figure 1. Typical WSN architecture

2. LITERATURE SURVEY

Wireless sensor networks positioning are of great importance in advanced control and tracking systems with the development of modern technologies which made a large number of researchers to study for multiple scientific methods aiming for the same purpose which is to find the location of non-GPS wireless sensors in (WSNs) as following [11].

a. The methods of measuring the distance between the reference node and the sensor node such as time of arrival (TOA) technique which depends on measured the distance by calculating the time that the signal takes when sending it from the sensor node until it's arrived to reference node [12]. The (TDOA) technique depends on measured the difference in time of arrival between two signals until they reach the same reference node [13]. The (FDOA) technique depends on measured of the phase difference between two signals for two elements of the antenna [14]. And the (RSSI) technique is calculating the strength of the incoming signal by comparing the signal strength and the expected distance for propagation the distance is estimated [15]. It must be noted that all measurement methods above lack accuracy and their inability to locate multiple sensor.
b. Another location technique called position calculation techniques it depend on the mathematical way of calculating the site by relying on three or more reference nodes such as (TST) Trilateration scanning technique [16, 17] it summarizes to find the location of a sensitive node between three reference nodes located at the intersection point of the three circles whose centre is the reference nodes. The (TM) triangulation method is done by drawing a triangle between two reference nodes and the sensitive node and use mathematical calculation to find the location [18, 19]. The other positioning method is (PML) pattern matching localization it is depends on matching the received signal with the other recorded signal as a reference [20, 21]. This method have a good accuracy but high expensive because it needs a large number of reference nodes and their inability to locate multiple sensor.
c. Positioning algorithm: in this technique, the distance and the position information are group to enhancement and mapping the node location accurately [22] by used MUSIC algorithm to calculate or estimate the angles of the signals received from the sensitive sensors that are received by the array antenna [23]. The MUSIC algorithm is based on analysing the data matrix and then extracting the arriving angles [24]. This method is characterized by high speed in dealing with multiple signals and accuracy of the results but there is drawback in this method which can't to estimate the angles for the coherent signals.

3. PROBLEM STATEMENT

In this paper assume that there is no prior knowledge about the position of the target nodes. The random deployment of wireless sensor networks WSN produces the problem of locating and it is impossible to take advantage of the data of these sensors without known their location then because of the problem to use of the GPS system for each sensor, which is represented by (cost, size, and environmental impact). Therefore, it is necessary to use an appropriate method to find nodes location without using GPS technique [9, 10].

4. THE (MUSIC) ALGORITHM

It was projected in 1979 by SCHMEDT. (MUSIC) produced a new epoch of spatial algorithms for direction finding these algorithms that have characterized grow and improvement and it became a key algorithm for the spatial spectrum system. The methodology of its summarized in the following steps [25].

4.1. Array signal flow

The first step of MUSIC algorithm methodology is the signal flow of the array antenna. Figure 2 shows the uniform linear array (ULA) with sensors number N allow it receive a narrow band Sk(t) source signals from the desired users coming from different angle. The array also receives K narrowband source signals arriving at directions (θ1, θ2... θK), [26, 27].

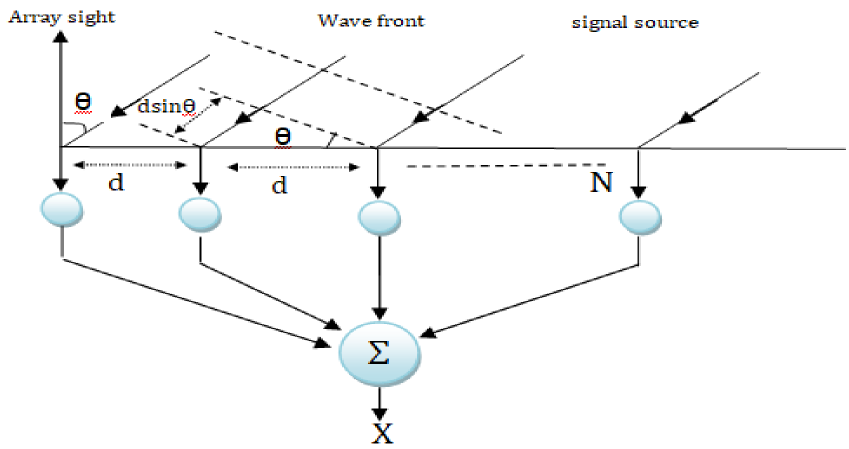

Figure 2. Signal flow in (ULA)

Let's $S_k(t)$ is the source signal and as matrix is

$$S = [S_1(t), S_2(t), \ldots, S_K(t)]^T \quad (1)$$

Then as a matrix. A are denoted to the steering vector of antenna element [28].

$$A = \begin{bmatrix} a_1(\theta_1) & a_1(\theta_2)\cdots & a_1(\theta_k) \\ a_2(\theta_1) & \ddots & \vdots \\ \vdots & \ddots & \vdots \\ a_n(\theta_1) & \cdots\cdots & a_n(\theta_k) \end{bmatrix} \quad (2)$$

$a_n(\theta_k)$: denoted to the element of array antenna impacted on the received signal represented as,

$$a_n(\theta_k) = exp\left[-j(n-1)\frac{2\pi\, dsin\,\theta_k}{\lambda}\right] \quad (3)$$

where;
λ: is the wavelength.
d: is the array elements spread,
θ: is the angle of arriving signal,

The spatial harmonic noise $n_n(t)$ and as a matrix

$$N = [n_1(t), n_2(t), \ldots, n_N(t)]^T \quad (4)$$

Then the array output as a matrix X became

$$\mathrm{X} = \mathrm{AS} + \mathrm{N} \quad (5)$$

The correlation (covariance) matrix R_X is

$$\mathrm{R_x} = \mathrm{XX^H} \quad (6)$$

$(.)^H$: Hermitian matrix (conjugate transport) [29, 30].

4.2. Theory of WSN localization by estimated DOA of nodes signal

Estimating the angle of arrival of the sensor signal produces WSN localization as flowing. Computation of Eigen decomposition of correlation matrix of array signal the RX matrix have an Eigenvalues sorted in descending form which is;

$$\lambda_1 > \lambda_2 > \ldots > \lambda_N > 0, \quad (7)$$

The bigger Eigenvalues for (K) number are matching to signal and the (N-D) lesser Eigenvalues are matching to the noise. Therefore, can be signal (Eigenvector, Eigenvalue) and noise (Eigenvector, Eigenvalue) [30]. The noise Eigenvalue is orthogonal to any column of the matrix A, where any row of the matrix A represents the source signal therefore it can be finding the direction of the source signal as a result of the orthogonally of the noise vector with the vector of matrix A so the first rows are devoted to the source signal [31] where the noise Eigenvector is V_N can be construct as matrix E_n.

$$\mathrm{E_n} = [\mathrm{V_{D+1}}, \mathrm{V_{D+2}}, \ldots, \mathrm{V_N}] \quad (8)$$

The spatial spectrum Pmu (θ) is defined as:

$$\mathrm{P_{mu}}(\theta) = \frac{1}{a^H(\theta) E_n E_n^H a(\theta)} \quad (9)$$

The denominator became zero of value at the arrived angle but in real because existing of the noise, it is in fact smallest and then P_{mu} (θ) has a peak value. By this procedure the angle of arrival is finding by make θ change and estimates the peak [32, 33]. The flowchart of MUSIC algorithm shows in Figure 3.

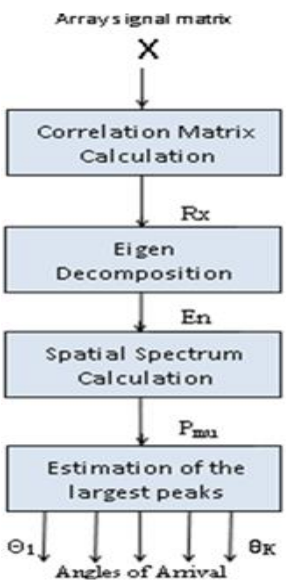

Figure 3. MUSIC algorithm flowchart

5. MODIFIED MUSIC (M-MUSIC) ALGORITHM

The MUSIC algorithm is good for the spatial spectrum estimation of incoherent signals. But when signal sources are coherent it fails to detect them measure it as a one signal. This is a drawback hindering the use of this algorithm in important and large networks. then the independent signal sources that received by the array will decrease which lead to the array correlation matrix rank reduce and the number of larger eigenvalues less than the incoming signal spatial spectral curve does not present the peak thus cannot obtain the correct signal DOA estimation [34].

Hence to estimate the coherent signal DOA accurately must be remove the correlation between the signals. This section provides the method of modified MUSIC algorithm and improved it by planned the data matrix with conjugate reconstruction of MUSIC algorithm as in the following. Formulate a matrix transformation J is an Nth-order opposed matrix known transition matrix.

$$J = \begin{bmatrix} 0 & 0 & \cdots & 1 \\ 0 & 0 & 1 & 0 \\ \vdots & \vdots & \cdots & \vdots \\ 1 & 0 & \cdots & 0 \end{bmatrix} \tag{10}$$

The modified correlation matrix R_{XX} calculated from added reconstruction matrix to the correlation matrix as below [35].

$$R_{XX} = R_X + JR_X X^* J \tag{11}$$

The matrices RX and RXX have the same noise subspace according to matrices properties Figure 4. Shows the flow chart for (M-MUSIC) algorithm to carry out the decomposition characteristic of R_{XX} and obtain its Eigenvector and Eigenvalue denoted to the number of estimated signal source split the noise vector and then use this new noise vector to create spatial spectrum to determined or estimation the angle value of DOA by peak searching [35, 36].

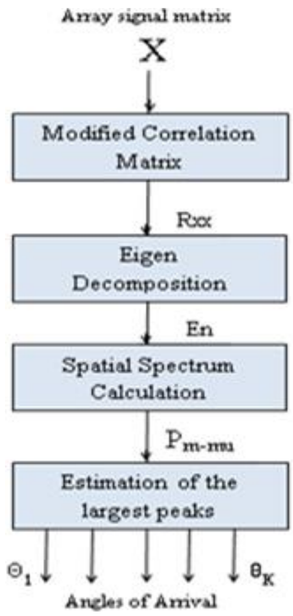

Figure 4. M-MUSIC algorithm flowchart

6. MATLAB SIMULATION

Design a MATLAB simulation of a WSN system consist of three node sensors randomly distributed at angle θ= (10º, 25º, 45º) respectively which are wirelessly connected to a reference node equipped with an (ULA) antenna have number of element N=4 and the element separate by 0.5λ and SNR 20dB programmed with the (MUSIC) or (M-MUSIC) algorithm to estimation of DOA and assume a specific environment the resulted as flowing.

6.1. Used incoherent signals

Test the performance of MUSIC and M-MUSIC algorithm with Independent (incoherent) narrow signal send from nodes received by (ULA) antenna at reference node Figure 5. Shows the simulation results which noted that the peaks of the chart symbolize the locations of the node sensors it symbolize the DOA which shows the efficiency of the MUSIC algorithm to estimation the node positioning with incoherent signals. When the above experiment is repeated with the same data by used (M-MUSIC) the modified algorithm the results as in Figure 6. It almost identical indicating the accuracy of the modified algorithm but we will discover the superiority of the (M-MUSIC) algorithm to estimation of DOA gives an improvement in the direction estimate since the width of the estimate signal band becomes narrow which gives more accuracy in reading.

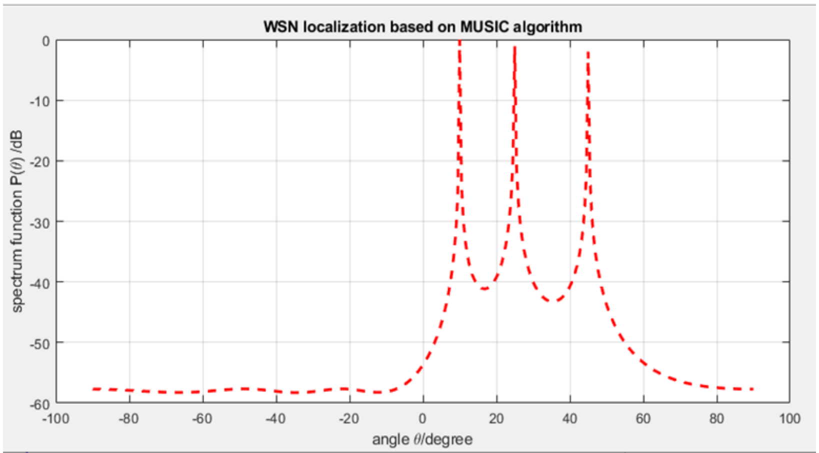

Figure 5. MUSIC with incoherent signal

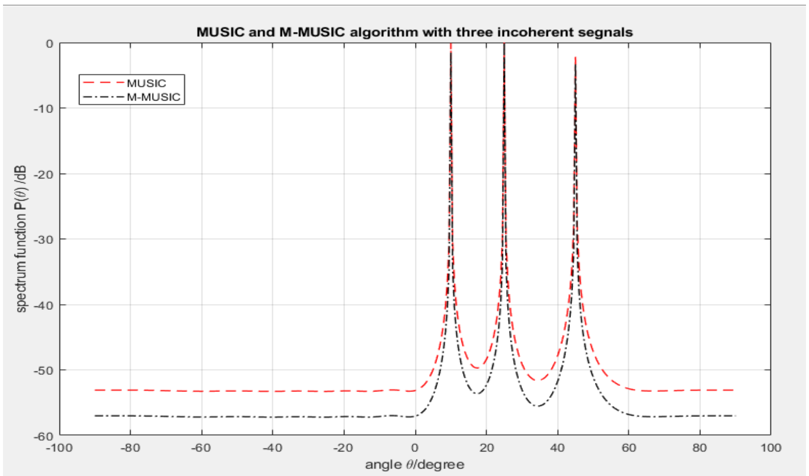

Figure 6. MUSIC, M-MUSIC with incoherent signal

6.2. Used coherent signals

In this section the previous experiment was repeated for the same data with three coherent signals from node sensors at different angles Figure 7. Shows the failure of the MUSIC algorithm in detection the three signals and showed the results as a one signal. While the M-MUSIC algorithm succeeded in discovering the three signals and identifying correct angles as in Figure 8.

Shows the difference between the two methods when detected the coherent signals the two experiments above shows that the MUSIC algorithm is efficient to estimating the angles of the wireless sensor signal if these signals are incoherent. But if the signals are coherent the MUSIC algorithm cannot distinguish between coherent signals and deals with them as a single signal. While the M-MUSIC algorithm able to detect the signals in both cases with high accuracy.

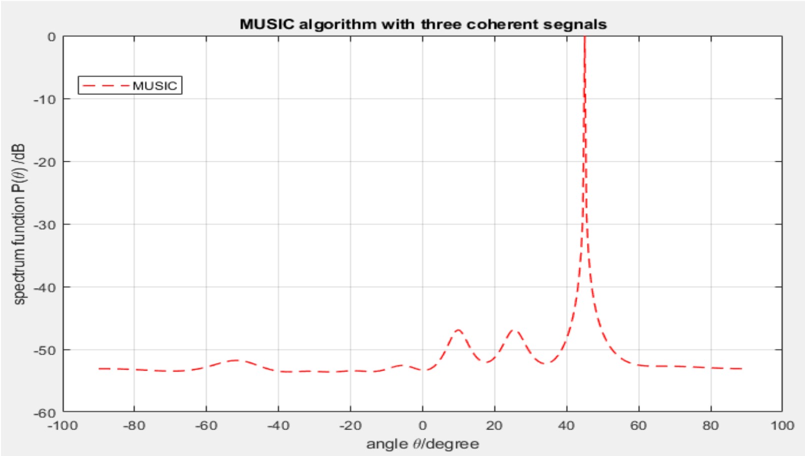

Figure 7. MUSIC with coherent signal

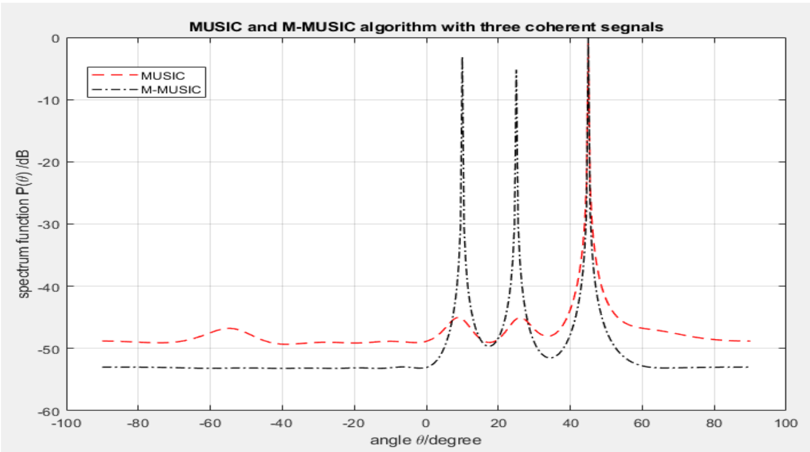

Figure 8. MUSIC, M-MUSIC with coherent signal

7. FACTORS AFFECTED ON THE RESULTS

For design positioning system by this algorithm with high quality it must be pointed out that there are several factors that affect the result accuracy of estimated the DOA when used both (MUSIC or M-MUSIC) algorithm to localization (WSNs) as the following.

7.1. Number of elements

To clarify the DOA estimation affected by the number of array elements we will repeat the previous simulations in section (6) with the same data, and a change the number of elements to (4, 10, and 40) the results in the following Figure 9. It is evident that the increase in the number of antenna elements gives an improvement in the direction estimate, since the width of the estimate signal band becomes narrow, which gives more accuracy in reading, and it must be noted that the increase in the elements is determined by cost and complexity factors and must be compatible with the nature and quality the work.

7.2. Array element spacing

To clarify the DOA estimation affected by the spacing of array elements we will repeat the previous simulations in section (6) with the same data, and a change the spacing of element (0.25λ, 0.5λ, λ) Figure 10. Show the results that increasing the distance between the elements of the antenna up to half the wavelength increases the efficiency of estimating the direction of the signal. But when the distance becomes greater than half the wavelength, there is an error in estimation of DOA, and in order to obtain the best results, the distance between the elements must be kept close to half the wavelength.

7.3. SNR

For the effected of SNR on DOA estimation and, we will repeat the previous simulations in section (6) with the same data, and a change the rate of SNR to (-30dB, 0dB and 30dB). Figure 11 shown the results. As shown in Figure 11, that the low values of SNR are inaccurate result of MUSIC algorithm when estimated DOA, and at increasing SNR, the width of the signal of DOA estimate band becomes narrow, resulting increasing the accuracy of the MUSIC algorithm.

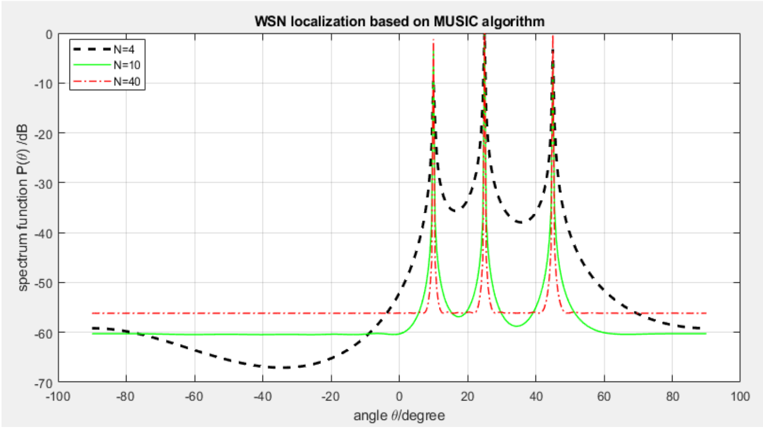

Figure 9. Number of element affected

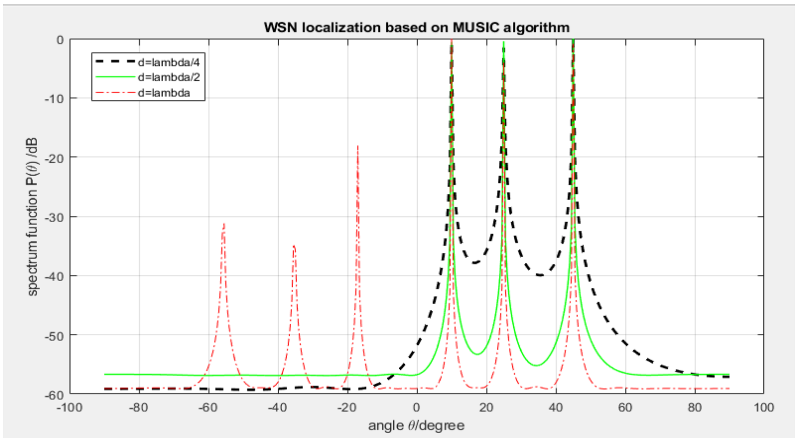

Figure 10. Spacing element affected

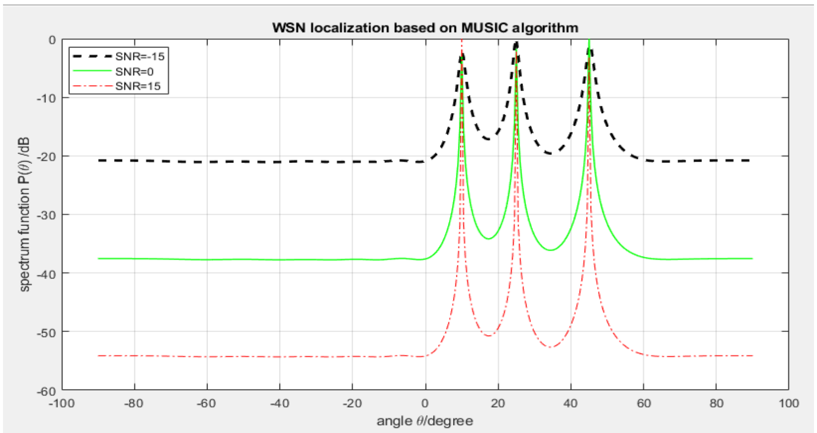

Figure 11. SNR affected

8. CONCLUSION

In this paper we examined the non-GPS positioning system for (WSNs) localization and tested the effectiveness of using the MUSIC algorithm to calculate the arriving angle of sensor signal but this algorithm failed to detection coherent signals and this is a weak point in the performance of this algorithm especially in large and important networks. The research showed how to develop this algorithm to modified MUSIC algorithm named M-MUSIC algorithm which has proven highly effective in detecting wireless sensor signals and estimated the DOA and proved successful to detection both coherent and non-coherent signals by used MATLAB simulation program. Therefore, the design non-GPS localization system for (WSNs) using M-MUSIC algorithm produces a highly efficient localization system. It must be noted that to enhancement the results must be chose large number of elements of (ULA) and increasing the distance between the elements of the antenna not exceed half the wavelength and (SNR) at high rate that can guarantee a good performance.

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