TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 12, No. 10, October 2014, pp. 7318 ~ 7329
DOI: 10.11591/telkomnika.v12i8.6493

Intelligent Linear Collaborative Beamforming for Multi-objective Radiation Beampattern in Wireless Sensor Networks

N.N.N.A. Malik*, M. Esa, S.K.S. Yusof, N.M.A. Latiff
UTM MIMOS CoE Telecommunciation Technology, Faculty of Electrical Engineering,
Universiti Teknologi Malaysia (UTM), 81310 UTMJB, Johor Bahru, Malaysia.
*Corresponding author, e-mail: noordini@fke.utm.my

Abstract

Collaborative beamforming (CB) in wireless sensor networks (WSNs) promises improvement of communication performance and energy efficiency. The random distribution sensor nodes location within WSNs can introduce random beampattern mostly in the sidelobe region. In addition, higher energy consumption can occur as the randomness permits the generation of high peaks in radiation beampattern performance. Therefore, selecting a suitable spatial sensor node distribution is a challenge especially for WSNs. Collaborative sensor nodes in random deployment which performs as linear antenna array (LAA) can influence the radiation beampattern. However, it leads to the degradation of LAA and WSNs performances. Hence, an optimum algorithm for implementing CB method should be designed that takes into consideration not only the beampattern performance, but also the geometrical location of selected active nodes which cooperatively form an array antenna. In this article, a new algorithm known as intelligent linear sensor node array (ILSA) is presented. It is developed through the application of the proposed hybrid least square improved particle swarm optimization (HLPSO) algorithm. The newly proposed ILSA is constructed by means of collaborative nodes selection. The size of side lobe level (SLL) can vary significantly with desired multi-objectives. Simulation results obtained showed significant improved performance of the radiation beampattern. Thus, this motivates for exploiting the newly-developed optimum method in node geometrical location strategies of WSNs.

Keywords: *collaborative beamforming (CB), linear antenna array (LAA), wireless sensor network (WSN)*

1. Introduction

As the demand for wireless sensor networks (WSNs) constantly grows, the requirement for higher transmission range, better coverage and improved communication reliability increases. Typical signal transmission issue requires sufficient gain by using a high gain antenna element or constructing an array of elements that operate coherently. However, in WSN environment, the randomness geometrical location of sensor nodes in transmitting an emitted signal presents a unique situation. The dense deployment of many nodes would not allow costly and complex high gain antenna to be used. Therefore, using the power of beamforming in the sensor node arrays is an excellent alternative. Individual sensor node has an omnidirectional antenna, which radiates power uniformly in all directions, i.e. 360°. However, most of the transmitted power is wasted while only a fraction of the transmitted power is useful, which propagates to the desired direction. Therefore, if multiple sensor nodes collaborate and coordinate their transmissions by sending the same signal, the propagating signals will interfere constructively. Thus, the total radiated power will increase and focus to the desired direction. Furthermore, collaborative beamforming (CB) in WSNs can effectively improve reliability and coverage by nulling patterns towards interferers, and the transmission range will also be increased.

Research on sensor networks using CB [1-4] have explored the effectiveness and compatibility of the transmission array on the randomly distributed sensor nodes. The effect of random motion by independent mobile sensor nodes has been discussed in [5]. The proposed relationship model has managed to reduce network overhead and power usage in a wireless network structure. Ref. [6] refined a specific analysis on focusing energy in a desired direction using a combination of time difference of arrival (TDOA) and adaptive beamforming technique.

Received May 16, 2014; Revised July 15, 2014; Accepted August 10, 2014

The energy savings methodology has also been investigated in [7] to provide better defined beamwidth and compensate the effect of grating lobes. Two different methods are proposed with least mean square (LMS) implementation. These works mainly investigate the performance of beamforming using the theory of random arrays.To date, little attention has been paid to linear arrays for CB in linear arrays. However, alternative approaches have been linked to random array node implementation. Works on the linear array proposed by [8] has been further developed and reported [9-12]. In [13], an iterative approach that can be employed in scenarios where the individual nodes do not have knowledge of their location has been proposed. Papalexidis [8] and Malik [12] utilize a least square line fitting technique (LFA) to select the optimal nodes to participate in the distributed array.

A challenge with implementing beamforming in WSNs is that the sensor nodes are located in random distribution. In this work, the optimization of sensor node location problem is investigated where a large number of nodes are available to take part in this beamforming action. Obviously, the array gain performance improves with increasing number of elements (i.e. sensor nodes). However, the nodes in WSNs have limitations in energy consumption, computation power and communication ranges, which means that it is inappropriate for all available nodes to take part in this CB action. Consequently, selecting only suitable nodes from the available active cluster (*AC*) to perform beamforming is of research concern. In the preliminary version of this work [11], it was shown that the linear sensor nodes array (LSNA) is able to achieve a comparable adaptive beampattern with narrow main lobe and acceptable sidelobes level (SLL). This paper extends earlier work reported in [14, 15]. Novel concept is offered in regards to intelligently optimizing the selected sensor nodes to participate and form an array of sensor nodes by employing intelligent linear sensor node array (ILSA) based on the swarm intelligence algorithm [16]. This new algorithm of ILSA with combination of novel hybrid least square improved-PSO (HLPSO) has been proposed to suit the WSNs requirement. The swarm algorithm has been chosen as the problem solver because of its flexibility, versatility and ability to optimize in complex multimodal search spaces.

The main idea of the proposed method is the desired multi-objectives of radiation beampattern with minimum SLL, desired main beam angle and size of first null beamwidth (FNBW). The proposed intelligent method of ILSA for determining optimum location of sensor node is proved superior to alternate technique in terms of the normalized power gain. The remainder of this article is organized as follows. Section 2 provides an overview of the system modelling and array factor. Section 3 explains the HLPSO-based ILSA method. Section 4 presents an analysis of the proposed method. The last section summarizes the paper.

2. The System Model and Array Factor

WSNs consist of a large number of sensor nodes; which are wirelessly connected in random position. The nodes are self-organized and are in contact with a controlling station as described in [3]. Each of this sensor node's location is determined using location discovery techniques [7] and is reported back to the controller. The controller has detailed knowledge of each of the sensor node's location. These nodes then form a different cluster with regards to the selected manager node (*MN*). The controller is also capable of selecting the appropriate *MN*, thus active cluster (*AC*) as per user requirement. Each of the sensing nodes, S_z is able to sense the environment and collect its own data. The selected *MN* gathers the data from the sensing nodes and then multicast a final data packet to all the selected collaborative sensor nodes, i.e. active CB nodes. The data from these sensing nodes are aggregated at the *MN* and only the needed information will be multicasted. The active CB nodes will collaboratively transmit the same data in a synchronous manner. These active CB nodes; which perform as an array antenna have the possibility of forming a narrow highly directive beam to the intended target point, where the receivers (base stations) may be positioned in order to collect all the transmitted data sent by collaborative nodes.

The collaborative array antenna radiates power in all directions, therefore it is assumed that all sensor nodes are located on a 3-dimensional *x-y-z* plane. The geometrical model configuration of the randomly deployment sensor nodes and the target point is illustrated in Fig. 1. As shown, there are three different sets of sensor nodes (i.e. active/transmit mode, idle mode and sleep mode). Active mode indicates a node in active state and transmitting collected data. Idle mode indicates a node in active state but waiting to transmit data. The sleep mode indicates a node in sleep state with very minimal energy usage. Both active and idle nodes are within the *AC* while the sleep mode nodes are outside the *AC*.

The proposed system is formed by a network of *Z* stationary sensor nodes randomly placed at position $S_z = (s_1, s_2,..,s_Z)$. Each sensor node is denoted in Cartesian coordinate (x_k, y_k) with *k* denotes the number of nodes while the location of target point is given in spherical coordinates, $P\ (p, \theta_0, \phi_0)$, where p, θ_0, and ϕ_0, are the distance between the target point and the reference point, desired elevation and azimuth angle, respectively. The angle $\phi \in [-\pi,\pi]$ represents the azimuth direction and $\theta \in [0,\pi]$ represents the elevation direction. The following assumptions are adopted in considering this model operation:

(a) Sensor nodes are assumed to lie in the *x-y* plane in random deployment inside the region of interest of Λ m^2.
(b) Mutual-coupling effects among the antennas of different sensor nodes are negligible. No signal reflection or scattering, thus multipath fading or shadowing.
(c) The location of target points, *P* is at the far-field region from the *AC* with desired angle of ϕ_0 and θ_0.
(d) All nodes are stationary and energy constrained.
(e) All nodes are capable of operating as a *MN* either in active, idle and sleep modes.

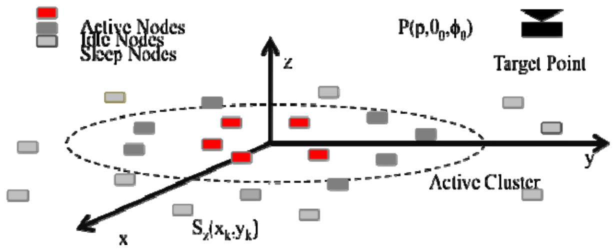

Figure 1. Definition of Notation

Consider a 3-dimensional characteristic of *N*-element LAA placed at the *x-y-z* plane. Assume *z* = 0, therefore the plane is visualized to run parallel to the earth's surface. The array factor, *AF* of the LAA is referred by [17]:

$$AF(\theta,\phi) = \sum_{n=1}^{N} e^{j\xi_n} e^{j\alpha_n} \tag{1}$$

Both the current signal phase, ξ and the synchronizing phase weights, α can be determined by:

$$\xi_n = \kappa(x_n sin\theta cos\phi + y_n sin\theta sin\phi + z_n sin\theta) \tag{2}$$

$$\alpha_n = -\kappa(x_n sin\theta_0 cos\phi_0 + y_n sin\theta_0 sin\phi_0 + z_n sin\theta_0 \tag{3}$$

Where κ, θ, ϕ, x_n and y_n are the wave number $\kappa = 2\pi/\lambda$ with λ is the wavelength, elevation angle, azimuth angle, *x*-coordinate and *y*-coordinate (x_n, y_n) of the *n*th element, respectively. θ_0 and ϕ_0 are the maximum radiation angles.

The power gain *G* is then given by [17]:

$$G(\theta,\phi)_{dB} = 20\log_{10}|AF(\theta,\phi)| \tag{4}$$

And the normalized power gain G_{norm} in decibel [17]:

$$G_{norm}(\theta,\phi)_{dB} = 10\log_{10}\left[\frac{|AF(\theta,\phi)|^2}{\max|AF(\theta,\phi)|^2}\right] \tag{5}$$

3. Proposed Methodology Description

3.1. Proposed Hybrid Least Square Improved-PSO Algorithm (HLPSO)

PSO is employed to determine the optimum distance location of the nodes; which performs the best within the objective scopes. Some improvements have been adopted in original PSO [16] in order to overcome the weaknesses and to adapt the algorithm inside WSNs environment. The novel HLPSO is proposed by adopting two novel mechanisms, i.e. constraint boundaries variables and particle's position and velocity reinitialization. Moreover, the least square approximation algorithm (LS) is integrated into it to improve the effectiveness and the capabilities of PSO in ILSA application.

The modifications and improvements that have been done in HLPSO are discussed as follows:

3.1.1. Global Constraint Boundaries Variables

Two sets of global constraints boundaries variables for lower boundary, L and upper boundary, U for different position particles, d_{s1} and d_{sn} (n=2,3,…N) is adopted and represented as:

$$L_1 \le d_{s1} < U_1 \tag{6}$$

$$L_N \le d_{sn} < U_N \tag{7}$$

These two boundaries are applied to restrict d_{s1} and d_{sn} to stay inside the solution space. Additionally, maximum upper limit and minimum lower limit are also assimilated inside this proposed HLPSO, i.e. U_{max} and L_{min}, respectively. These two limits are determined before the computation of the objective function, of in order to enhance the diversity of the particle's searching abilities to be more global and freedom. Thus, it is expressed as:

$$d_{s1} = \begin{cases} d_{s1} = L_1 \xrightarrow{yields} of(L_1), & if\ d_{s1} > U_{max} \\ d_{s1} = d_{s1} \xrightarrow{yields} of(d_{s1}), & if\ L_{min} \le d_{s1} < U_{max} \\ d_{s1} = L_1 \xrightarrow{yields} of(L_1), & if\ d_{s1} \le L_{min} \end{cases} \tag{8}$$

And

$$d_{sn} = \begin{cases} d_{sn} = L_N \xrightarrow{yields} of(L_N), & if\ d_{sn} > U_{max} \\ d_{sn} = d_{sn} \xrightarrow{yields} of(d_{sn}), & if\ L_{min} \le d_{sn} < U_{max} \\ d_{sn} = L_N \xrightarrow{yields} of(L_N), & if\ d_{sn} \le L_{min} \end{cases} \tag{9}$$

3.1.2. Particle's Position and Velocity Reinitialization

The random numbers of particle position, d_{sn} can be a factor of the particle's tendency to leave the initially defined search space. Therefore, a modification based on the absorbing wall conditions by [18] is implemented in this algorithm. In order to control the movement of particle from flying outside the border of the search space, the velocity, v_{sn} is zeroed whenever the particle, d_{sn} goes over the boundary U_N and L_N. However, the particle, d_{sn} are then pulled back inside the search space by reinitializing it as random numbers, r generated from the values of [L_{min},U_{max}]. The objective of this reinitialization of d_{sn} is to prevent the particle from being stucked in local optima scenario where the particle is trapped and inhibited to search for a better solution. By introducing the reinitilization, a more flexible and comprehensive searching can be done by the particle with noted limitations, as expressed by equations below:

$$v_{sn} = \begin{cases} v_{sn} = 0 \rightarrow d_{sn} = r[L_{min}, U_{max}], & if\ d_{sn} > U_N \\ v_{sn} = v_{sn}, & if\ L_N \le d_{sn} < U_N \\ v_{sn} = 0 \rightarrow d_{sn} = r[L_{min}, U_{max}], & if\ d_{sn} \le L_N \end{cases} \tag{10}$$

By using Equation (10), the particle movement maybe triggered again so that it has the higher probability to search for the optimum global best. In addition, the particle position is also forced to stay inside the upper boundary, *U* and lower boundary, *L* as denoted by following equations:

$$d_{s1} = \begin{cases} d_{s1} = U_1, & if\ d_{sn} > U_1 \\ d_{s1} = d_{s1}, & if\ L_1 \le d_{sn} < U_1 \\ d_{sn} = L_1, & if\ d_{sn} \le L_1 \end{cases} \tag{11}$$

And,

$$d_{sn} = \begin{cases} d_{sn} = U_N, & if\ d_{sn} > U_N \\ d_{sn} = d_{sn}, & if\ L_N \le d_{sn} < U_N \\ d_{sn} = L_N, & if\ d_{sn} \le L_N \end{cases} \tag{12}$$

The integration of the LS approximation algorithm in this HLPSO is required so that the desired radiation beampattern performance can be closely approximated to the desired beampattern results. Due to the random spatial positioning of nodes, LS algorithm provides the ability to alter and create a radiation beampattern by introducing weights on each node. The determination of the weights allows elimination of the effect of random nodes position errors in WSNs. The effect of weights can be removed through equalization.

3.2. Optimization Methodology Setup of ILSA

The number of participating CB nodes, *N* is also initialized which are represented as Q_n= (q_1,q_2,..,q_N). These CB nodes are in active modes. The communication radius, *C* of *MN* has been identified at this stage. The distance between two nearby CB nodes is $\lambda/2$, which depends on the operating frequency, *f*. The initial parameters for WSNs environment are shown in Table 1.

The proposed optimization setup scheme of ILSA is described as follows:

Step 1. Construct the virtual line β that passes through the *MN*.

Step 2. Establish the HLPSO algorithm.

Step 2a. Initialize HLPSO parameter as in Table 2.

Step 2b. Randomly generate initial location *D* and velocity *V* for each particle in an *N*-dimensional problem with *S* particles:

$$D = [d_{sn}] = [d_{s1}, d_{s2}, d_{s3}, \dots \dots d_{sN}]\ subject\ to\ D \in [0\lambda, 2\lambda] \tag{13}$$

$$V = [v_{sn}] = [v_{s1}, v_{s2}, v_{s3}, \dots \dots v_{sN}]\ subject\ to\ V \in [0, 0.2] \tag{14}$$

Step 2c. Calculate objective function i.e. *of* or *mulobj* of each d_{sn}, i.e. *of* (d_{sn}) or *mulobj*(d_{sn}).

$$minimize\ mulobj \tag{15}$$

$$subject\ to\ d_{sn} \in D \tag{16}$$

$$mulobj = (w_1 \cdot of_{SLL}) + (w_2 \cdot of_{nu}) + (w_3 \cdot of_{bw}) \tag{17}$$

Where:

of_{SLL} is the objective function of SLL minimization term as defined in:

$$of_{SLL}(\theta_{SLL}) = \sum_{SLL_1=1}^{MaxSL} |AF(\theta_{SLL_1})|_{dB} + \sum_{MinSL}^{SLL_2=181} |AF(\theta_{SLL_2})|_{dB} \tag{18}$$

Where θ_{SLL1} and θ_{SLL2} are the angles where the SLL is minimized in the lower band (from $\theta_{SLL1=1}$ to $\theta_{SLL1=MaxSL}$) and in the upper band (from $\theta_{SLL2=MinSL}$ to $\theta_{SLL2=181}$), respectively. *AF*□ is the array factor as in equation (1).

of_{nu} is the objective function of null placement term as defined in:

$$of_{nu}\left(\theta_{nu_\varsigma}\right) = \sum_{\varsigma=1}^{\varsigma} |AF\left(\theta_{nu_\varsigma}\right)|_{dB} \quad (19)$$

Where ς and $\theta_{nu\varsigma}$ are the number of nulls and the location angles of null placements, respectively.

of_{bw} is the objective function FNBW term as defined in:

$$of_{bw}(\theta_{bw}) = \sum_{bw=bw1}^{bw2} |AF(\theta_{bw})|_{dB} \quad (20)$$

Where θ_{bw} is the angle of desired FNBW, i.e. FNBW=θ_{bw2} - θ_{bw1} which is the range of angles of the major lobe.

w_i, i=1,2,3 is the user-defined constants that control the contribution from each term of sub-objective to the overall objective function. It is usually assumed that $\sum_{i=1}^{3} w_i = 1$ and the value of w_i is determined based on the user-desired objectives.

Step 2d. Determine the previous best location, *pbest*, $P=[p_s]= [p_{1,},p_{2,},p_{3,\ldots}p_S]$. Set $of(p_s)$ value equal to $of(d_{sn})$ or $mulobj(d_{sn})$.

Step 2e. Determine the global best position, $G=[g_n]=[g_1,g_2,g_3,..,g_N]$. Set $g_n=min(p_s)$ or $g_n=optimum(p_s)$.

Step 2f. Update *V:*

$$v_{sn}(\tau+1) = \omega v_{sn}(\tau) + c_1 r_1[p_s(\tau+1) - x_{sn}(\tau)] + c_2 r_2[g_n(\tau+1) - x_{sn}(\tau)] \quad (21)$$

Where c_1 and c_2 are acceleration constants, r_1 and r_2 are uniformly distributed numbers in [0,1]. τ+1 and τ refer to the time index of the current and previous iterations. ω is the inertial weight factor. Then, limit *V* using equation (10).

*Step 2g.*Update *D*:

$$d_{sn}(\tau+1) = d_{sn}(\tau) + v_{sn}(\tau+1) \quad (22)$$

And limit *D* of the particles by using Equation (11) and (12).

Step 2h. Update *pbest* as follows:

If $of(d_{sn})$ or $mulobj(d_{sn})$ is better than *of(ps)* or $mulobj(p_s)$, then update p_s and store $d_{sn}(p_s)$.

Step 2i. Update *gbest* as follows:

If $of(p_s)$ or $mulobj(p_s)$ is better than $of(g_n)$ or$mulobj(g_n)$, then update g_n and store $d_{sn}(g_n)$.

Step 2j. If the maximum iteration number is met, stop algorithm, else go to *step 2c.*

Step 3. By using the optimized distance, d_{sn} obtained from previous process, construct a LAA on the virtual line γ, which is perpendicular to the virtual line β. The constructed LAA is assumed having *N*-nodes with spacing distance of d_{sn}. The sensor node location of *x*- and *y*-coordinate, E_n (x^E_n, y^E_n) is referred to the values of d_{sn}:

$$\sqrt{[(x_{n+1}^E - x_n^E)^2 + (y_{n+1}^E - y_n^E)^2]} = d_{s(n+1)} \quad (23)$$

Where n=1,2,….N nodes element. The construction of this optimum LAA is illustrated in Fig. 2.

Step 3a. Determine gain and normalized gain, G^E and G^{normE} by using equations (4) and (5), respectively.

Step 4: The optimum LAA, E_n cannot be performed practically as the sensor nodes are randomly distributed (uniform random distribution) inside WSNs field.

Step 4a. Search the minimum Euclidean distance, d^{min}_n between E_n (x^E_n, y^E_n) and the nearest node inside *AC*, $O_{zs}(x^O_{zs},y^O_{zs})$.

$$\min\{\sqrt{[(x_n^E - x_{zs}^O)^2 + (y_n - y_{zs}^O)^2]}\} = d_n^{min} \quad (24)$$

With *zs*=1,2,….*ZS* nodes inside *AC*.

Step 4b. Select the O_{zs} which has d^{min}_n with coordinate (x^O_{zs},y^O_{zs}).

Step 4c. Activate O_{zs} and assign it as an optimum ILSA. ILSA denoted as $S_n(x^S_n, y^S_n)$, $S_n \in O_{zs}$. The mapping process is illustrated in Figure 3.

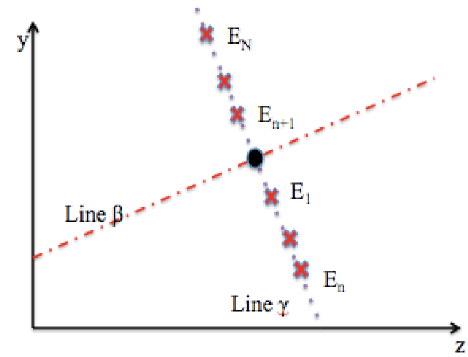

Figure 2. System Model of the Proposed ILSA

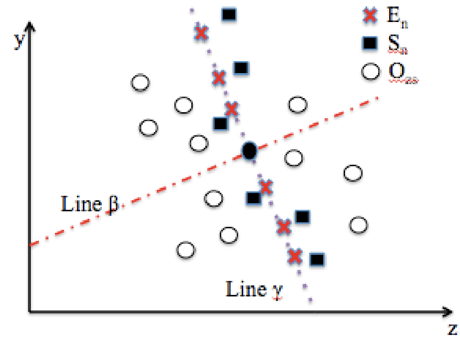

Figure 3. Locations of E_n, O_{zs} and S_n inside *AC*

Step 4d: This set of optimized nodes i.e. ILSA will act collaboratively as an *N*-element distributed LAA. Determined gain and normalized gain, G^S and G_{norm}^S for this newly optimal ILSA by using equations (4) and (5). All these ILSA denotes in active mode, i.e. active CB nodes.

Step 5. Start LS approximation method.

Step 5a. Calculate the desired weight coefficient, w^E_n

$$w_n^E = \exp\{j\kappa(x_n^E sin\theta_0 cos\phi_0 + y_n^E sin\theta_0 sin\phi_0)\} \quad (25)$$

Step 5b. Calculate the desired steering coefficient, d^E_{nm}

$$d_{nm}^E(\theta) = \exp\{jk(x_n^E sin\theta cos\phi_0 + y_n^E sin\theta sin\phi_0)\} \quad (26)$$

Where θ is elevation angle, $\theta \in$ {-180°,180°} and (*m*=1,2,..361)

Step 5c. Calculate the desired array response, F^E_{nm}:

$$F_{nm}^E(\theta) = w_n^E d_{nm}^E \quad (27)$$

Step 5d. Calculate the actual steering coefficient, d^S_{nm}

$$d_{nm}^S(\theta) = \exp\{jk(x_n^S sin\theta cos\phi_0 + y_n^S sin\theta sin\phi_0)\} \quad (28)$$

Step 5e. From F^E_{nm} and d^S_{nm}, calculate actual weight coefficient, w^S_n

$$w_n^S = d_{nm}^{S+} F_{nm}^{ET} \quad (29)$$

Where F^{ET}_{nm} is the transpose of F^E_{nm} and d^{S+}_{nm} is the pseudo inverse of the transpose d^S_{nm}.

Step 5f. From w^S_n, calculate the final array factor of $S_n(x_n^S, y_n^S)$ active ILSA CB nodes as per written equation:

$$AF^S(\theta,\phi) = \sum_{n=1}^{N} w_n^{*S} \exp\{jk(x_n^S sin\theta cos\phi + y_n^S sin\theta sin\phi)\} \quad (30)$$

Where w_n^{*S} is the complex conjugate of w_n^S

Step 6. Determine gain, G^{ILSA} and normalized gain, G_{norm}^{ILSA} of final ILSA as per

Equation (4) and (5).

Step 7. In order to form the most promising performance of LAA:

Step 7a. Rotate virtual line β in counter clockwise direction with different angle ϕ as shown in Figure 3.

Step 7b. Return to *Step 1* for different angle rotation of virtual line β

Step 7c. Compare the radiation beampattern performance results from different rotations.

Step 7d. Select the best solution.

Step 8. End

The rewards then associated with this proposed methodology are the design objective on the desired radiation beampattern with minimum SLL, desired main beam angle and expected size of beamwidth in comparison with previous LFA [8].

Table 1. List of Parameters used in WSN Scheme Implementation of ILSA

Number of nodes	Z	900
Region of interest	Λ m^2	900 m^2
Number of CB nodes	N	(8,12,16)
Communication radius	C m	(6m, 8m, 14m)
Angle of interest	$(\theta_{0,}, \phi_0)$	$(\theta_{0,}, \phi_0)$

Table 2. List of Parameters and Values used in HLPSO Implementation

Number of particles	S	30
Dimension of particles	N	(8,12,16)
Iterations	It	500
Range of particles	D	0 to $2\lambda_O$
Upper boundary for d_n	U_N	$2.2\lambda_O$
Lower boundary for d_n	L_N	$0.35\lambda_O$
Upper boundary for d_1	U_1	$2.2\lambda_O$
Lower boundary for d_1	L_1	$0.3\lambda_O$
Maximum upper limit	U_{max}	$0.1\lambda_O$
Maximum lower limit	L_{min}	$2.5\lambda_O$
Velocity	V	0 to 0.2
Learning factors	c_1=c_2	2.0
Maximum weight	ω_{max}	0.9
Minimum weight	ω_{min}	0.4

4. Simulation and Analysis

The key highlight in this new algorithm is the capability of selecting only the appropriate collaborative active nodes to perform as an array antenna which meets the desired multi-objectives. Therefore, in order to demonstrate the advantages of the proposed ILSA for the CB beampattern performance, several simulations in multiple scenarios, i.e. 8-, 12- and 16-node ILSA have been conducted to prove the performance of the proposed ILSA method compared to previous the LFA [8].

Case 1: Case 1 investigates the capability of ILSA to manage two desired objectives simultaneously, i.e. SLL minimization and adaptive angle, which are applied on 8-node ILSA and 12-node ILSA. An 8-node ILSA is simulated for desired main beam angle of -30° as in Figure 4. Results are compared to the corresponding results obtained using LFA. It is shown that the SLL suppression is improved. All the minor lobes have been minimized with the first SLL to be less than -16 dB i.e. -16.59 dB and the maximum SLL is -15.30 dB. The size of FNBW of ILSA maintains similarly as the FNBW of LFA, i.e. 43°. It can be inferred that the result shows a very excellent outcome.

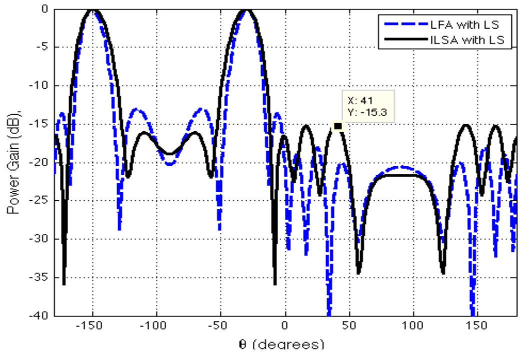

Figure 4. Radiation Beampattern of 8-node ILSA and 8-node LFA

The next array considered is a 12-node ILSA as shown in Figure 5. A first observation from these plots is that a good performance of radiation pattern is obtained from ILSA even with a 30° adaptive angle. For a FNBW of 30°, the SLL achieved is -15.03 dB as compared to the LFA, i.e. -12.68 dB. It can be inferred that the results show an acceptable outcome.

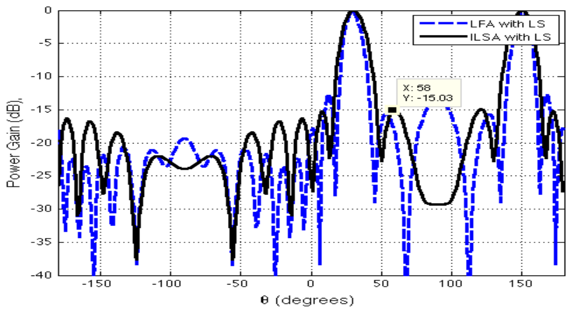

Figure 5. Radiation Beampattern of 12-node ILSA and 12-node LFA

Case 2: In this case, 3 desired objectives of SLL minimization, FNBW controllable and main beam desired angle are considered simultaneously as referred to Figure 6. 16-node ILSA is simulated and analyzed in order to prove the capability of this proposed algorithm to handle multi-objective requirements. The desired main beam angle is pointed to 25°. The size of FNBW by using 16-node ILSA (i.e. 52°) is adjusted to be larger than that obtained using 16-node LFA (i.e. 27°). In addition, the maximum SLL for 16-node ILSA outperformed LFA. The maximum SLL of -16.38 dB has been achieved by using ILSA as compared to high SLL by using LFA, i.e. -13.16 dB. It can be inferred that the result shows very excellent outcome.

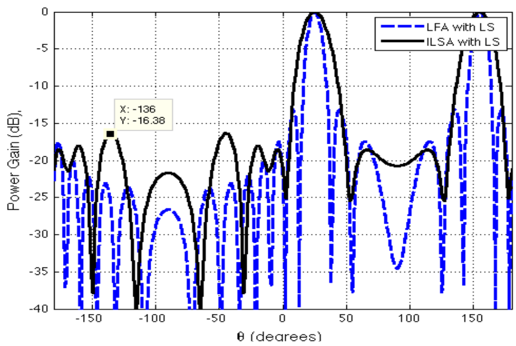

Figure 6. SLL Minimization, FNBW Controllable and Main Beam Angle Adaptable of 25°

Case 3: In this case, another main criteria is added which is the null placement. Therefore, four objectives will be counted as the focal multi-objectives in terms of (i) SLL minimization (ii) FNBW controllable (iii) main beam desired angle and (iv) null placements. These four different characteristics are needed to be simultaneously achieved. It can be seen from Fig. 7 that the 12-node ILSA achieves zero sidelobes at intended null placements of -40° and 40°, while the sidelobes of LFA are uncontrolled and high at the intended null placements. Moreover, it can be seen that all other minor lobes decreased significantly with maximum SLL of -21.46 dB at 90° compared to the higher sidelobes of LFA with maximum SLL of -12.88 dB at 17°. The normalized gain demonstrated maximum gain at θ_0=0°. The FNBW of 12-node ILSA is then optimized to be larger, i.e. 86°.

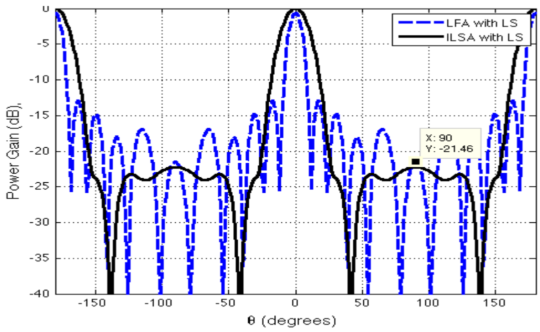

Figure 7. SLL Minimization, FNBW Controllable, Null Placement and Main Beam Angle adaptable of 0°

Next, the main beam of this 12-node ILSA is then steered to 25° as in Figure 8. As compared to 12-node LFA, ILSA achieves lower SLLs, wider FNBW up to 87°, nulling ability at -100° and 100° and finally adaptive angle towards 25°. It is obviously noted that this newly-proposed ILSA can satisfy these four conflicts by achieving the optimum radiation beampattern. It can be inferred that the result is very excellent.

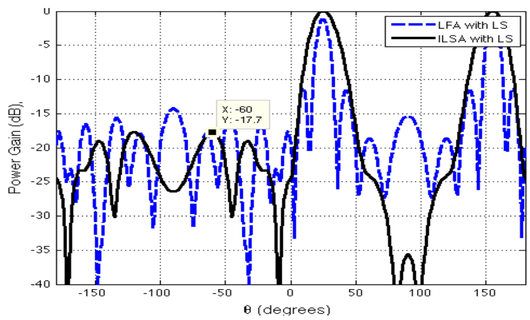

Figure 8. SLL Minimization, FNBW Controllable, Null Placement and Main Beam Angle Adaptable of 25°

Case 4: The final array considered is a 12-node ILSA with different multi-objective of specified ranges of nulls as depicted in Figure 9. The figure displays the resulting radiation pattern corresponding to the other two desired multi-objective designs of controlled FNBW and minimum SLL. For comparison purposes, LFA is also plotted in this figure. It can be verified that a good performance of radiation pattern is attained from 12-node ILSA as compared to the 12-node LFA. In particular, ILSA has zeros (deep nulls) at the angles specified to be located in the range $\theta_{nu}\in$[60° 120°]. Note that all curves are enforced to be low values with maximum SLL of -15.29 dB. The size of FNBW noticeably increases up to 50°.

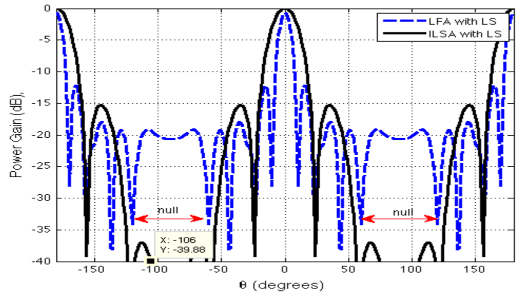

Figure 9. SLL Minimization, FNBW Controllable, Null Placement Located in the Range $\theta_{nu} \in$ [60° 120°]

5. Conclusion

A method of intelligent CB algorithm for sensor nodes has been successfully developed as presented in this article. Several multi-objectives (e.g. main beam adaptive capability, FNBW controllable, null placement and SLL minimization) were taken into considerations. The optimization results and analysis presented indicate that CB can be effectively realized by utilizing the proposed HLPSO based-ILSA algorithm. The high-performance evolutionary algorithm, known as PSO algorithm is adopted and modified to become the proposed HLPSO algorithm. The technique presented here is intelligent, thus compatible to WSN scenario. Different numerical examples with different number of CB active nodes, objectives and considerations are presented to illustrate the capability of ILSA for radiation beampattern synthesis. It is found that by employing ILSA method, the results provide improvement over the conventional array and the other companion algorithm. The radiation beampattern performance of the proposed beamformer is derived and it is proven that beampattern associated with any arbitrary location of sensor nodes can converge to the desired various objectives.

Acknowledgements

We are grateful for the UTM and Ministry of Education Malaysia financial supprot for Fundamental Research Grant (FRGS) Scheme vote FRGS/2/2013/ICT03/UTM/03/2.

References

[1] Mudumbai R, Barriac G, Madhow U. *On the Feasibility of Distributed Beamforming in Wireless Networks*, Wireless Communications, IEEE Transactions on. 2007; 6(5): 1754-1763.
[2] Ochiai H, Mitran P, Poor HV, Tarokh V. *Collaborative beamforming for distributed wireless ad hoc sensor networks,* Signal Processing, IEEE Transactions on, 2005; 53(11): 4110-4124.
[3] Vincent P, Tummala M, McEachen J. *A new method for distributing power usage across a sensor network*, Ad Hoc Networks. 2008; 6(8): 1258-1280.
[4] Chen W, Wang D, Wang W. *Beamforming for information transfer in wireless sensor networks without perfect positioning*, Microwave Conference Proceedings. APMC 2005. Asia-Pacific Conference Proceedings. 2005; 3.
[5] Lintz WA, McEachen JC, Tummala M. *Sensor beamforming with distributed mobile elements in a wireless sensor network*, Electrical and Computer Engineering. CCECE '09. Canadian Conference on. 2009.
[6] Batson MS, McEachen JC. *A Method for Fast Radio Frequency Direction Finding Using Wireless Sensor Networks,* Hawaii International Conference on System Sciences, Proceedings of the 41st Annual. 2008.
[7] Batson M, McEachen J, Tummala M. *Enhanced Collection Methodology for Distributed Wireless Antenna Systems,* Presented at System of Systems Engineering. SoSE '07. IEEE International Conference on. 2007
[8] Papalexidis N, Walker TO, Gkionis C, Tummala M, McEachen J. *A Distributed Approach to Beamforming in a Wireless Sensor Network,* Signals, Systems and Computers, ACSSC 2007. Conference Record of the Forty-First Asilomar Conference on. 2007.
[9] Malik NNNA, Esa M, Yusof SKS. *Optimization of Node Coordination in Wireless Sensor Networks*, Conference on 6th Regional Student Conference on Research and Development (SCOReD 2008), Johor, Malaysia. 2008,

[10] Malik NNNA, Esa M, Yusof SKS. *Intelligent optimization of node coordination in Wireless Sensor Network*, Conference on Innovative Technologies in Intelligent Systems and Industrial Applications, CITISIA 2009. 25-26 July 2009, Kuala Lumpur. 2009: 328 – 331.
[11] Malik NNNA, Esa M, Yusof SKS. *Optimization of Adaptive Linear Sensor Node Array in Wireless Sensor Network*, Microwave Conference. APMC. Asia Pacific. IEEE Computer Society. 2009; 2336-2339.
[12] Malik NNNA, Esa M, Yusof SKS, Marimuthu J. *Optimising of Node Coordination in Wireless Sensor Network*, PIERS Proceedings, Moscow, Russia. 2009; 1235-1238.
[13] Vincent PJ, Tummala M, McEachen J. *A Beamforming Approach for Distributed Wireless Sensor Networks*, System of Systems Engineering, SoSE '07. IEEE International Conference on. 2007.
[14] Malik NNNA, Esa M, Yusof SKS, Hamzah SA. *Evaluation on optimum geometrical of linear node array for self-organization in a wireless sensor network*, Applied Electromagnetics (APACE), IEEE Asia-Pacific Conference on,. IEEE Computer Society. 2010; 1-5.
[15] Malik NNNA, Esa M, Yusof SKS, Hamzah SA. *Optimization of linear sensor node array for wireless sensor networks using Particle Swarm Optimization,* Microwave Conference Proceedings (APMC), Asia-Pacific. IEEE Computer Society. 2010; 1316-1319.
[16] Kennedy J, Eberhart R. *Particle swarm optimization, Neural Networks.* Proceedings. IEEE International Conference on. 1995.
[17] Balanis CA. Antenna Theory: Analysis and Design, USA: John (Wiley and Sons., 2005).
[18] Zaharis ZDK, Papastergiou A, Hatzigaidas A, Lazaridis P, Spasos M. *Optimal design of a linear antenna array using particlalae swarm optimization,* Proc. of the 5th WSEAS Int. Conf. on Data Networks, Communications and Computers. City: Bucharest (Romania), 2006; 69-74.