COLLABORATIVE BEAMFORMING FOR WIRELESS SENSOR NETWORK USING PARTICLE SWARM ANALYSIS

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ABSTRACT

In Wireless Sensor Network (WSN), nodes can collaborate to monitor, gather and select only the required data to transmit to the receivers. However, the nodes are working in uncertain hazardous environments that lead to undesirable high battery power consumption. Thus, it is desirable to improve radiation beampattern performance by introducing intelligent Collaborative Beamforming (CB) concept. It manages to increase the antenna gain and performance by aiming at desired objectives through intelligent capabilities. In this thesis, the nodes are designed to cooperate and collaborate among themselves and act as a collaborative antenna array. An optimal CB algorithm for intelligent sensor node array has been developed which combines CB and Particle Swarm Optimisation (PSO) in the presence of node geometry location uncertainties. The collaborative nodes are modelled in linear and circular array configurations. Firstly, a theoretical foundation employing CB inside WSN is developed consisting of three main stages: parameter initialisation, activation and optimisation setup. Then, newly proposed Intelligent Linear Sensor Node Array (ILSA) and Intelligent Circular Sensor Node Array (ICSA) are successfully optimised by applying Hybrid Least square improved PSO (HLPSO). The HLPSO has been developed using global constraint boundaries variables and, reinitialisation of particle's position and velocity. It incorporates with Least Square approximation algorithm. For intereference occurence case at six unintended receivers, ILSA manages to significantly suppress Sidelobe Level (SLL) up to 85.54% in average. For null placement, the peak SLL within the null ranges angles have been greatly minimised up to 103%. The ICSA with multi-objective optimisation has outstandingly reduced SLL to 213% with 36° First Null Beamwidth size increment. Both ILSA and ICSA can effectively improve radiation beampattern performance and coverage by intelligently adjusting the shape of the beampatterns under different constraints as per desired usage. So, it accomplishes significant improvements compared to the referenced CB algorithm.

ABSTRAK

Dalam Rangkaian Penderia Wayarles (WSN), nod penderia boleh bekerjasama untuk memantau, mengumpul dan memilih hanya data yang diperlukan untuk dihantar kepada penerima. Walau bagaimanapun, nod ini bekerja dalam persekitaran berbahaya yang meningkatkan penggunaan kuasa bateri. Maka, pencapaian alur sinaran perlu ditingkatkan dengan memperkenalkan konsep Kerjasama Pembentukan alur (CB) pintar. Ia dapat menambah gandaan dan pencapaian antena berdasarkan objektif yang diingini melalui keupayaan pintar. Dalam tesis ini, nod direka bentuk untuk saling bekerjasama dan bertindak sebagai antena tatasusunan. Satu CB optimum algoritma untuk tatasusunan nod penderia pintar telah dibangunkan dengan menggabungkan CB dan Teknik Kerumunan Zarah (PSO) dalam kehadiran ketidakpastian lokasi geometri nod. Nod kerjasama dimodel sebagai konfigurasi tatasusunan lelurus dan bulatan. Pertamanya, teori asas melibatkan CB dalam WSN dibangunkan. Ia terdiri daripada tiga peringkat: pemulaan parameter, pengaktifan dan pengoptimuman. Kemudian, tatasusunan nod penderia lurus pintar (ILSA) dan bulatan pintar (ICSA) berjaya dioptimumkan dengan menggunakan PSO kuasa dua terkecil hibrid (HLPSO). HLPSO dibangunkan dengan pembolehubah sempadan kekangan global dan, pemulaan semula kedudukan dan halaju zarah. Ia juga digabungkan dengan algoritma penghampiran kuasa dua terkecil. Bagi kes gangguan enam penerima yang tidak disengajakan, ILSA begitu berjaya menindas paras cuping sisi (SLL) sehingga 85.54% secara purata. Bagi penempatan nol, puncak SLL dalam julat sudut nol telah dikurangkan dengan jayanya sehingga 103%. ICSA dengan pengoptimuman kepelbagaian objektif telah mengurangkan SLL sebanyak 213% beserta peningkatan saiz lebaralur nol pertama sebesar 36°. ILSA dan ICSA berkesan meningkatkan prestasi pembentukan alur sinaran dan liputan dengan menyesuaikan bentuk corak alur mengikut kehendak pengguna secara bijak. Dengan ini, kemajuan yang signifikan dicapai berbanding algoritma CB yang dirujuk.

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AC	-	Active Cluster
ACO	-	Ant Colony Optimization
ADC	-	Analog to Digital Converters
AP	-	Access Point
BFA	-	Bacterial Foraging Algorithm
BS	-	Base Station
CAA	-	Circular Antenna Array
CB	-	Collaborative Beamforming
CSA	-	Circular Sensor Node Array
CT	-	Cooperative Transmission
DE	-	Differential Evolution
DNOI	-	Direction-Not-of-Interest
DOI	-	Direction-of-Interest
DSP	-	Digital Signal Processing
FNBW	-	First Null Beamwidth
GA	-	Genetic Algorithm
HLPSO	-	Hybrid Least Square Improved Particle Swarm Optimization
ICSA	-	Intelligent Circular Sensor Node Array
ILSA	-	Intelligent Linear Sensor Node Array
ImPSO	-	Improved Particle Swarm Optimization
LAA	-	Linear Antenna Array
LFA	-	Least Square Line-Fitting Linear Array
LMS	-	Least Mean Square
LS	-	Least Square
MN	-	Manager Node
Pdf	-	Probability Density Function

SLL	-	Sidelobe Level
SNR	-	Signal to Noise Ratio
UAV	-	Unmanned Aerial Vehicle
UCA	-	Uniform Circular Array
ULA	-	Uniform Linear Array
WSN	-	Wireless Sensor Network
τ	-	Current time index
ω_{max}	-	Maximum value of the weighting factor
ω_{min}	-	Minimum value of the weighting factor
It	-	Iteration
X_{min}	-	Lower boundary for X
X_{max}	-	Upper boundary for X
U_{max}	-	Maximum upper limit
L_{min}	-	Minimum lower limit
of	-	Objective function
κ	-	Wavenumber
In	-	Excitation amplitude of nth element of LAA
βn	-	Phase of nth element of LAA
θ	-	Elevation direction
ϕ	-	Azimuth direction
dn	-	Location of the nth element of LAA
θ_0	-	Desired elevation angle
D	-	Range of particles
I	-	Number of elements for CAA
d_i	-	Location of the ith element of CAA
θ_i	-	Angle of incidence of ith element of CAA
k	-	Number of nodes
Z	-	Stationary nodes
S_z	-	Position of stationary nodes
x_k	-	x-coordinate of stationary nodes
y_k	-	y-coordinate of stationary nodes
p	-	Distance between target point and reference point

θ_0	-	Desired elevation angle
ϕ_0	-	Desired azimuth angle
A	-	Region of interest
C	-	Communication radius
ρ	-	Density of the nodes
x_{MN}	-	x-coordinate of MN
y_{MN}	-	y-coordinate of MN
X	-	Area of AC
Z_S	-	Total number of nodes within AC
x_i	-	x-coordinate of I observant data
y_i	-	y-coordinate of I observant data
d_i	-	Residuals of I observant data
I	-	Number of ULA elements
U_i	-	Location of i-element ULA
λ	-	Wavelength
c	-	Velocity of light
f	-	Frequency
n_i	-	Neighbor node of i-element ULA
Q_i	-	Location i-nodes LFA
G	-	Gain
G_{norm}	-	Normalized Gain
r^{UCA}	-	Radius of UCA
A_i	-	Location of i-element UCA
R_i	-	Location i-node CSA
ε	-	Error Euclidean distance
ε_{ave}	-	Average total error Euclidean distance
x_i^U	-	x-coordinate of of i-element ULA
y_i^U	-	y-coordinate of of i-element ULA
x_i^Q	-	x-coordinate of of i-node LFA
y_i^Q	-	y-coordinate of of i-node LFA
x_i^A	-	x-coordinate of of i-element UCA
y_i^A	-	y-coordinate of of i-element UCA
x_i^R	-	x-coordinate of of i-node CSA

y_i^R	-	y-coordinate of of i-node CSA
N	-	Number of elements/active CB nodes
AF	-	Array factor
ξ	-	Current signal phase
α	-	Synchronizing phase weights
x_n	-	x-coordinate of of n-element LAA
y_n	-	y-coordinate of of n-element LAA
ς	-	Number of nulls
θ_{nu_ς}	-	Location of nulls
B	-	Number of SLL bands
$MinSL$	-	Lower band range of SLL
$MaxSL$	-	Upper band range of SLL
θ_{SLL1}	-	Angles where the SLL is minimized in the lower band
θ_{SLL2}	-	Angles where the SLL is minimized in the upper band
θ_{bw1}	-	Lower range of mainlobe
θ_{bw2}	-	Upper range of mainlobe
w_i	-	User-defined constants
$mulobj$	-	Multi-objective function
$F^{real}{}_m$	-	Actual array response vector
$W^{real}{}_n$	-	Actual weight vector
$D^{real}{}_{nm}$	-	Actual steering vector
$n\text{x}m$	-	Column vector
$F^{des}{}_m$	-	Desired array response
W_n	-	Desired weight vector
$D^{des}{}_{nm}$	-	Desired steering vector
$F^{T\ des}{}_m$	-	Transpose of $F^{des}{}_m$
$D^{+real}{}_{nm}$	-	Pseudo inverse of $D^{T\ real}{}_{nm}$
$D^{T\ real}{}_{nm}$	-	Transpose of $D^{real}{}_{nm}$
m_1	-	Virtual line slope 1
c_1	-	Offset of the origin of virtual line slope 1
m_2	-	Virtual line slope 2
c_2	-	Offset of the origin of virtual line slope 2
E_n	-	Location n-node ImPSO-based LAA

x_n^E	-	x-coordinate of of n-node ImPSO-based LAA
y_n^E	-	y-coordinate of of n-node ImPSO-based LAA
λ_0	-	With regards to $\lambda/2$
O_{zs}	-	Location zs-node LAA inside AC
$x^O{}_{zs}$	-	x-coordinate of of zs-node LAA inside AC
$y^O{}_{zs}$	-	y-coordinate of of zs-node LAA inside AC
S_n	-	Location n-node ILSA
$x^S{}_n$	-	x-coordinate of of n-node ILSA
$y^S{}_n$	-	y-coordinate of of n-node ILSA
B_n	-	Location n-node ImPSO-based CAA
$x^B{}_n$	-	x-coordinate of of n-node ImPSO-based CAA
$y^B{}_n$	-	y-coordinate of of n-node ImPSO-based CAA
(r^d,ϕ_n)	-	Polar coordinates of of n-node ImPSO-based CAA
r^{ICSA}	-	Radius for ICSA
M_n	-	Location n-node ICSA
$x^M{}_n$	-	x-coordinate of of n-node ICSA
$y^M{}_n$	-	y-coordinate of of n-node ICSA
w_n	-	Weight coefficient for LS
d_{nm}	-	Steering coefficient for LS
F_{nm}	-	Array response for LS

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CHAPTER 1

INTRODUCTION

1.1 Research Background

This thesis presents a development of new optimal collaborative beamforming (CB) concept inside an environment of wireless sensor networks (WSNs). Well-established concepts including routing network protocol and random array beamforming are challenged by the sensor node limitations in terms of power and computational capabilities. New algorithms are proposed with regards in conducting two different optimal CB algorithms for intelligent sensor node arrays, thus optimizing the multi-objectives radiation beampattern performance. Emphasis is placed on the investigating effects of random node deployment on the array beampattern schemes. Each of these schemes is justified and compared to the conventional process in terms of related system performance.

WSNs are the combination of systems which consist of devices with sensing, computation and communication functions (Chen *et al.*, 2002). WSNs have been actively applied in military and civilian applications. The sensor node device in WSNs can be deployed quickly and left un-attended by humans. The deployment can be structured and unstructured manners (Yick *et al.*, 2008). In unstructured WSNs, a dense collection of nodes may be deployed in an ad-hoc manner while in the structured WSNs, fewer nodes are placed in pre-planned manner or at specific known locations.

Sensor node is the most fragile hardware that depends on the reliability and life period. It is equipped with one or multiple on-board miniature sensors (such as for chemical, optical, motion, and imaging), a power supply, a transceiver for short-range communication links and also a memory and processor (Akyildiz *et al.*, 2002a). The miniaturization and intelligence of the devices have enabled their ubiquitous and invisible deployment either uniformly or randomly in very large quantities inside private residences, industrial plants, civilian areas or military environments. These sets of sensor nodes are very attractive since they can sense, measure, collaborate, and gather information from the monitored phenomenon. Based on some local decision processes, they can transmit only the needed information to other locations or receivers i.e. base stations (BSs) or access points (APs) for processing and interpretation.

WSN applications require a wide area of sensor nodes to communicate with far BSs or APs. The limited power and computational capabilities of individual sensor nodes can trigger new challenge in communication between nodes-nodes or nodes-BSs or APs as the transmission range of individual nodes is in short distance (Akyildiz *et al.*, 2002a). Well-established concepts of wireless technology and array beamforming have been introduced to overcome the aforementioned limitations. The high density deployment of nodes has been exploited to set up alternative communication schemes in WSNs (Ahmed and Vorobyov, 2009a). Positively, by introducing wireless technology, communication between sensor nodes can outperform wired connection in severe environment. However, one of the significant issues in wireless communication is the decrement of the received signal-to-noise power ratio (SNR) at the receiver. Thus, the technique of CB has been integrated inside WSNs environment. It is a concept that nodes can collaborate with other nodes in the network in some manner that increase their effective operation, such as the transmission range (Mudumbai *et al.*, 2007; Ochiai *et al.*, 2005) and received SNR. CB is also a strong means to establish a reliable and energy-efficient communication (Zarifi *et al.*, 2010; Feng *et al.*, 2010a) as it avoids the dependence of communication quality on individual nodes. Besides, it also distributes power consumption among the collaborative nodes and balances their lifetime (Zhu and Poor, 2007). Additionally, CB builds direct single-hop communication link, either for transmission and reception, from the collaborative nodes to the distant intended BSs or APs that may be located far beyond the transmission range. Thus, it will overcome issues in multi-hop technology in WSNs. Therefore, it also introduces less communication delay and data overhead.

In WSNs, sensor nodes are normally equipped with single omnidirectional antenna (Vincent *et al.*, 2006). If these nodes transmit their data to the distant receivers, it would be more efficient if they collaborate and share their transmitting message and simultaneously transmit the identical message to the intended direction of distant receivers. The signals from all the sensor nodes are transmitted and combined coherently at the desired receiver, and results in a more robust channel with higher signal-to-noise-ratio (SNR) and improved in energy-efficiency (Feng *et al.*, 2010b). In CB concept as shown in Figure 1.1, consider the sensor nodes collect their own data and form an active cluster. Sensor nodes in the active cluster are in active modes. Sensor nodes in the same cluster then transmit the common message synchronously to the same receiver. At the receiver, the individual signal from each node arrives in phase and constructively added. Therefore, by taking the benefit of the number of nodes, an array of sensor nodes can be constructed to increase the antenna gain (Litva, 1996), thus the communication range (Feng *et al.*, 2010b). For example, by assuming that each transmitter node has the same transmitted power and free-space attenuation, N collaborating nodes perform beamforming that can result up to N^2 power gain in the received power at the receivers. It can intensify the transmission range by N times farther. As an option, each transmitter node can reduce its power to $1/N^2$ for the same distance (Feng *et al.*, 2010a). In WSNs, an alternative of a single intelligent antenna structure with desired objective may be impractical in size, implementation or cost.

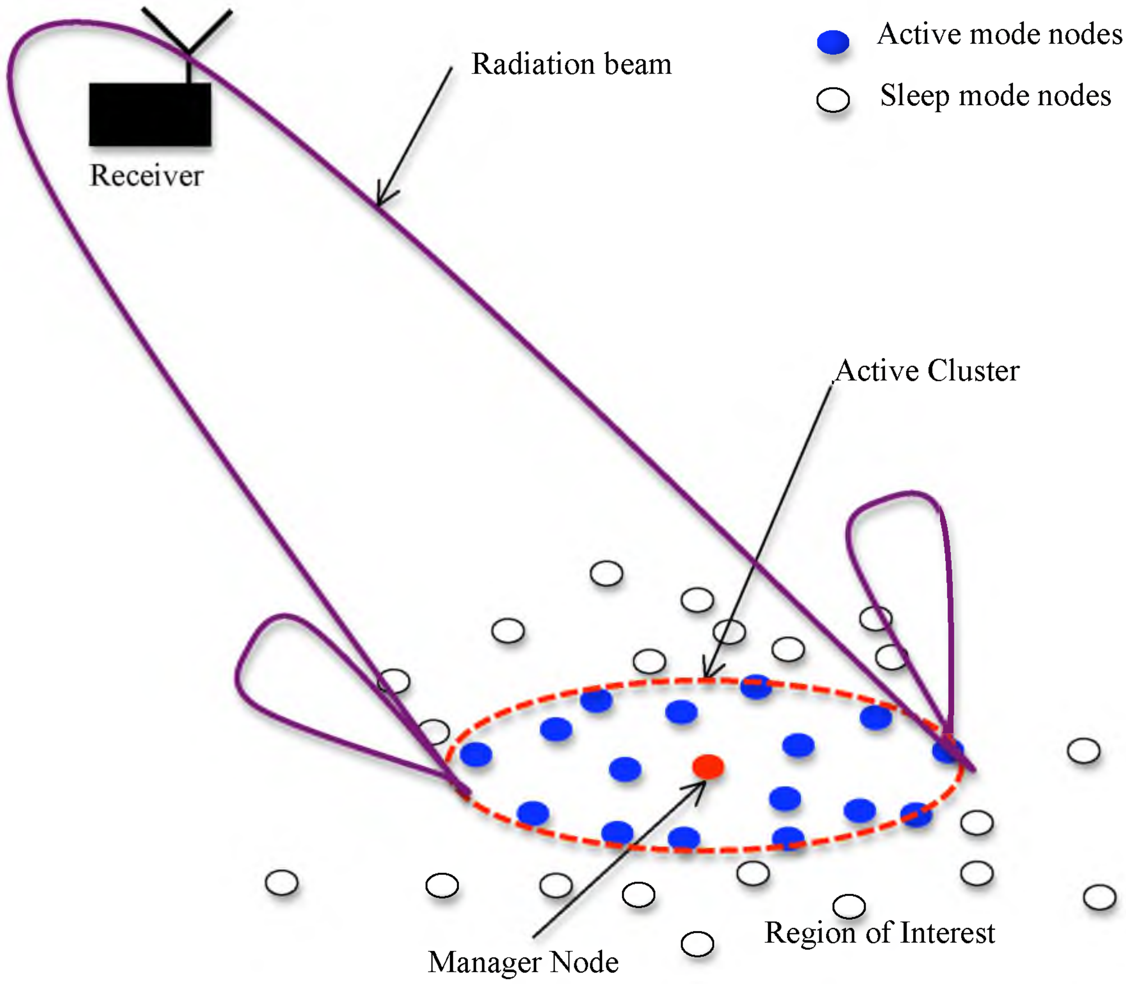

Figure 1.1 The Collaborative Beamforming Concept in Region of Interest of WSNs

Therefore, there is an immediate need to integrate a CB capability in order to produce the directional beam that can increase the main beam power and transmission range, and filter out the interference. The tradeoff between the intelligent capabilities, position distribution errors and radiation beampattern performance of the CB inside WSNs has to be optimized. In addition, CB also manages to improve data security by reducing or completely eliminating signals at undesired signals (Feng *et al.*, 2009). The research focuses on developing optimal CB algorithm of geometrical nodes array in randomly deployed sensor field. The main objective is to evaluate different approaches by employing selected array configurations such as linear and circular. Firstly, the research shall concentrate on a low complexity yet important and widely-applied case, the linear array, named as intelligent linear sensor node array (ILSA). Although linear array is appealing for its simple form, it has an inherent limitation of angle surveillance. Therefore, a circular array, named as intelligent circular sensor node array (ICSA) is also studied and proposed, which brings major advantage of maintaining the beampattern almost invariant (Hong, 2005) with little change in either beamwidth or the sidelobe level (Ioannides and Balanis, 2005) throughout 360° azimuth angles. The research work will be based on the development of new algorithms of ILSA and ICSA through the application of proposed hybrid least square improved particle swarm optimization (HLPSO) algorithm. The developed algorithm will be able to estimate the performance of antenna gain in the presence of sensor node geometry location uncertainties. The proposed optimum algorithm will take into consideration not only the beampattern performance, but also the geometrical location of selected active CB nodes which cooperate to form an array antenna. The selective CB active nodes can vary significantly with desired objectives and performance evaluation metrics. As of date, the literature of beamforming in WSN has no reported work on these linear and circular array configurations for intelligent CB capability in WSNs.

1.2 Problem Statement

Two main problem statements that need to be addressed and resolved are summarized as below:

i) Position distribution error of sensor nodes - In CB, the carrier phase is adjusted by every node in order to cancel out the phase difference due to the propagation delay. These signals are then added coherently at the intended destination. The placement of participating CB nodes is also a critical matter as it contributes to the variations of carrier phase. The random position of nodes is also a factor to generate random sidelobes pattern because sidelobes corresponding to different sets of CB nodes are different.

ii) Radiation beampattern performance - The randomness placement of sensor nodes has high impact on sidelobe level (SLL) performance. SLL of beampattern severely depend on the locations of collaborative sensor nodes (Ahmed and

Vorobyoz, 2009a). The existence of high SLL can contribute an unacceptable interference to the unintended BSs or APs. Previous literatures on CB inside WSNs did not consider the variation of first null beam width (FNBW) size (Papalexidis *et al.*, 2007). Therefore, the size of FNBW cannot be controlled and strictly depended on the position of CB nodes. Narrow beampattern mainlobe, i.e. narrow FNBW manages to concentrate the transmitted power to the intended direction while dissipating only negligible power in other directions. However, such beampattern needs two strategies, firstly, a large number of participated nodes and secondly, sensor nodes need to be scattered in a large area within the network. This, however, will increase the energy efficiency with the high participation of nodes and affect the inter-connection between the nodes and consequently, obstructs the implementation of CB in practice (Zarifi *et al.*, 2009c).

Satisfying these two constraints inside WSNs can be very challenging issues. The research challenge is to design an optimal CB algorithm for intelligent sensor node array. The algorithms proposed new configurations, which manage to overcome issue in random distribution and intelligently optimize radiation beam performance besides increasing the transmission range and capabilities in WSNs environment.

1.3 Research Objective

The goal of this research is to develop a new algorithm that can determine the desired radiation beam of sensor nodes array for random WSN nodes deployment using collaborative beamforming (CB). Specifically, the objective of the work is to develop two optimal CB algorithms for intelligent sensor node array in linear and circular, i.e. intelligent linear sensor node array (ILSA) and intelligent circular sensor node array (ICSA), respectively. The algorithms are based on the principle of particle swarm optimization (PSO) algorithm (Kennedy and Eberhart, 1995) by introducing a newly hybrid least square improved PSO (HLPSO) algorithm. The nodes selected should be aligned in specified configurations with intelligent capabilities to optimize the desired objectives. Four performance metrics are considered; i.e., SLL suppression, null placement, controllable FNBW and desired multi-objectives.

1.4 Research Methodology

The research methodologies are:

(i) Assess available CB technologies, sensor node configurations and evolutionary algorithms in a WSN.

(ii) Develop a new algorithm based on PSO algorithm to search for optimum distance between elements in linear antenna array (LAA) and circular antenna array (CAA). Analyze its performance on the radiation beam performance in terms of SLL suppression, null placement, controllable FNBW and multi-objectives on both LAA and CAA.

(iii) Comparison of the developed PSO-based model and three previous models (Balanis, 2005; Panduro *et al.*, 2005; Panduro *et al.*, 2008b).

(iv) Develop a new algorithm of linear and circular sensor node array configuration by applying the previous developed PSO-based algorithm. Analyze its performance in terms of beam characteristics and optimization capability in array form.

(v) Simulate the developed linear and circular array for optimizing radiation beams in WSN applications by using MATLAB software (Stearns and David, 1996). Analyze the characteristics and optimization capabilities.

(vi) Analyze the performance of the proposed algorithms in terms of SLL suppression, null placement, controllable FNBW, multi-objectives, desired main beam angle, effect of different configurations, multiple base stations deployment and occurrence of interferences located nearest to the mainlobe.

(vii) Comparison of the developed model with previous models (Papalexidis *et al.*, 2007, Balanis, 2005).

A set of performance evaluation metrics to be used for evaluating the performances of the proposed algorithms are as follows:

(i) SLL suppression (Suppressing radiation lobe in any direction other than the direction-of-interest (DOI) and mainlobe).

a. For the proposed improved particle swarm optimization (ImPSO), the SLL must be comparable or less than SLL of conventional ULA or uniform circular array (UCA) (Balanis, 2005) and with other LAA from companion genetic algorithm (GA) methods (Panduro *et al.*, 2005; Panduro *et al.*, 2008b).
b. For the proposed ILSA and ICSA, the SLL must be comparable or less than SLL of line-fitting linear array (LFA) (Papalexidis *et al.*, 2007) and circular sensor node array (CSA) or conventional UCA (Balanis, 2005), respectively.

(ii) Null placement (Placing nulls at any arbitrary directions in the interfering signals or direction-not-of-interest (DNOI) nulls).
a. For the proposed ImPSO, the SLL must be zero at the desired nulling angles as compared to conventional uniform linear array (ULA) (Balanis, 2005).
b. For the proposed ILSA and ICSA, the SLL must be zero at the desired nulling angles as compared to the LFA (Papalexidis *et al.*, 2007) and CSA or conventional UCA (Balanis, 2005), respectively.

(iii) Controllable FNBW (FNBW is defined as a measure of the mainlobe, normally presented in degrees).
a. For the proposed ImPSO, the size of FNBW must be narrower or wider than the size of FNBW of conventional ULA (Balanis, 2005).
b. For the proposed ILSA and ICSA, the size of FNBW must be narrower or wider as compared to the LFA (Papalexidis *et al.*, 2007) and CSA or conventional UCA (Balanis, 2005), respectively.

(iv) Multi-objectives (The term multi-objectives are employed to evaluate two or more performance metrics simultaneously in order to obtain the radiation beampattern performance that represents the best compromise among the objectives, i.e. SLL suppression, null placement, controllable FNBW and main beam angle).

a. For the proposed ImPSO, the performance of multi-objectives must be better than LAA from companion GA methods (Panduro *et al.*, 2005; Panduro *et al.*, 2008b).

b. For the proposed ILSA and ICSA, the performance of multi-objectives must be better than the LFA (Papalexidis *et al.*, 2007) and CSA or conventional UCA (Balanis, 2005), respectively.

1.5 Research Contributions

The new concept of optimal CB algorithms on linear and circular intelligent sensor node array are developed for WSNs. These new algorithms are based on the principle of particle swarm optimization (PSO) algorithm (Kennedy and Eberhart, 1995) by introducing a newly-modified HLPSO algorithm. The following have been identified to be the main original contributions to the knowledge in CB inside WSNs environment:

(i) Intelligent Linear Sensor Node Array (ILSA) - With the existence of restrictions in multi hop transmission, it is valuable if the communication system in WSNs would allow the nodes to access the receivers (APs or BSs) directly; which do not burden other nodes with relaying tasks (Kalis *et al.*, 2010). The proposed HLPSO-based ILSA overcomes the demand of long distance communication by forming an assembly of sensor nodes in linear geometrical configuration. The selected nodes act collaboratively as a virtual LAA for radiation beam optimization, resulting in a more robust channel with increase in transmission range. The proposed approach, HLPSO-based ILSA uses selected nodes, i.e. active ILSA CB nodes, which are placed in linear configurations in order to perform a CB, instead of burdening all the nodes inside the active cluster (AC).

(ii) Intelligent Circular Sensor Node Array (ICSA) - The circular array does not have any edge elements. A circular array is a great option when steering through

360° is required. It manages to maintain its SLL and beamwidth changes. The circular arrays have been found advantageous in dealing with mutual coupling effect (Rattan *et al.*, 2009). The HLPSO-based ICSA is proposed for CB in WSNs where the CB active nodes are selected in circular configurations. The algorithm is able to achieve significant improvements in dealing with any objectives, compared to the other CB algorithm in the literatures. This HLPSO-based ICSA is also an alternative approach of CB method besides HLPSO-based ILSA. Verification results are defined to prove that this algorithm can tackle the desired objective or any multi-objectives, simultaneously.

(iii) Hybrid least square improved particle swarm optimization algorithm (HLPSO) - The original PSO has a high convergence speed. However, it is easy to fall into local optima (Chen *et al.*, 2005b) and it also appears to be lacking global search ability (Li *et al.*, 2008). Hence, some improvements have been introduced in this PSO to overcome the weaknesses. The proposed improved PSO (ImPSO) is proposed by introducing two mechanisms, i.e. global constraint boundaries variables, and reinitialization of particle's position and velocity. The effectiveness and capabilities of the proposed ImPSO are then assessed by synthesizing the LAA and CAA. In order to realize this intelligent algorithm in WSNs constraints, the ImPSO algorithm is combined with least square (LS) approximation algorithm, i.e. HLPSO. HLPSO manages to amend the radiation beampattern of CB performance. The proposed algorithm has been utilized in constructing both linear and circular array configurations inside WSNs environment, by considering random nodes distributions.

(iv) Sidelobe level (SLL) Suppression - Suppress SLL can focus the main beam power towards the DOI and decrease the output power to the DNOI. The existence of unacceptable interference to the unintended receivers (BSs or APs) can also be discarded by suppressing any high SLL generated from the randomness placement.

(v) Null Placement - In the absence of any unintended receivers (BSs or APs) at any particular angles, the null placement may be treated as design parameters that can be adjusted, either by imposing nulls or suppressing sidelobe peaks at the design angles considerably smaller than those from conventional ULA and previous works

(Papalexidis *et al.*, 2007; Balanis, 2005). This null-placement technique is to suppress interference on any desired particular angles.

(vi) Controllable first null beamwidth (FNBW) - In this proposed method, the FNBW of the radiation pattern can be controlled based on the selective active CB nodes either in linear or circular configurations. The advantages of the proposed method are that it can either increase or decrease the size FNBW to be narrower, or wider without any increment in the number of active CB nodes or cluster size.

(vii) Multi-objectives - From the extensive literature review done, this multi-objectives optimization problem for CB in WSNs has not been dealt before. Generally, when two or more conflicting design criteria are taken into account, the method will be more complex and larger time consuming. The proposed method manages to overcome complex design and deal with a few multi-objective requirements, simultaneously.

1.6 Thesis Organization

The remaining chapters of the thesis are organized as follows:

In Chapter 2, the basic principles of beamforming technology in various applications are reviewed. The fundamental theory of antenna which focus on the existing antenna arrays, i.e. LAA and CAA are also discussed in this chapter. Then, the basic principles of WSN architecture, including the detail function of sensor nodes are discussed. A review on the beamforming technology and computational intelligence (CI) inside WSNs are also described in this chapter. Next, a review on the evolutionary algorithm is provided. Detailed description of the PSO and its various applications on antenna array are given. Besides that, another evolutionary algorithm, i.e. GA is also briefly discussed. Additionally, the strengths of PSO over GA are also presented.

Chapter 3 presents the proposed ImPSO algorithm. Two mechanisms, i.e. global constraint boundaries variables and reinitialization of particle's position and velocity are described in detailed. Comprehensive simulations of this proposed algorithm by implementing both LAA and CAA are carried out. Furthermore, the performance of ImPSO algorithm is compared with other companion algorithms, genetic algorithm (GA) and conventional arrays.

The proposed CB design concept of four different concepts of LFA, CSA, proposed ILSA and proposed ICSA are first discussed in Chapter 4. This chapter describes the three main stages of the algorithm including the assumptions and definitions before these concepts are implemented. The least-square line fitting method is discussed in detail in order to construct LFA. The design concept of both LFA and CSA are discussed in detail. In addition, the proposed ILSA and ICSA are also discussed briefly in this chapter. Finally, simulations are carried out to investigate the properties of LFA and CSA. The results are discussed in depth.

In Chapter 5, an ILSA is proposed. This algorithm takes into account the random node deployment in defining the active CB nodes to take part in CB. The ILSA algorithm is discussed in details. In addition, series of simulations are conducted using different number of nodes and objectives to evaluate the performance of this algorithm, along with other companion algorithm in the literature that are designed for WSNs. Comparisons are made between the algorithms in order to show the benefit of using ILSA in handling the random node with desired objectives.

In Chapter 6, an ICSA is proposed to overcome the weaknesses and as an option to ILSA. Instead of using linear configuration, this algorithm utilizes a circular configuration that can fulfill the requirements of any stated objectives. The procedure of algorithm is provided. An analysis on radiation beampattern performance is verified by using simulation. The last chapter concludes the thesis. Contributions are presented and possible future works are proposed.

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