Optimising of Node Coordination in Wireless Sensor Network

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Abstract—Beamforming has been introduced in Wireless Sensor Networks (WSNs) in order to increase the transmission range of individual sensor nodes. One approach of optimizing node coordination is by implementing the theory of linear array for beamforming method. The approach is presented in this paper. The linear sensor node array (LSNA) is constructed within random sensor node deployment. The LSNA is optimized as a conventional uniform linear array (ULA) to minimize the position errors which will improve the beamforming performance in terms of gain, transmission range and characteristics. A simulation model is implemented to study the adaptive LSNA. Several scenarios were evaluated by comparing with the theoretical results of conventional ULA. The performance of the constructed adaptive LSNA demonstrated an excellent agreement compared to the conventional ULA.

1. INTRODUCTION

Wireless sensor networks (WSNs) have been extensively researched and analyzed in the communication research community. One significant issue that exists in WSN applications is the requirement to transmit data over long distance using individual power-constrained sensor node. By using a limited power source, these sensor nodes in WSNs have very limited lifetime thus contribute to the issues of restricted communication and computing capabilities [2]. Nevertheless, the transmission range of sensor nodes can be improved based on the beamforming theoretical [3, 4]. In WSN environment, the sensor nodes can be deployed in the form of clusters within the random deployment. In these clusters, the sensor nodes act collaboratively as a set of small non-directional antennas to simulate a large directional antenna. Each sensor node will share the data with other sensor nodes in the cluster before synchronously transmitting it to the receiver. The nodes can cooperate to coordinate their radiated transmission into a narrow beam that increases the transmission range. Thus, it can concentrate the radiation power in the desired direction whilst decrease the power loss in other directions.

Recently, there has been increased attention in using advanced beamforming technologies in WSNs. Implementation of beamforming algorithms in WSNs environment made use of signal processing techniques [5, 6]. Most of the reported work analyzes the performance of beamforming using the theory of random arrays. The random topology condition will generate phase errors thus affecting the performance of the antenna array. Hence, resulting in degraded beamformer performance, compared to that of an array of equally spaced fixed elements. Works on the linear array have been proposed [7, 8] to overcome such random deployment issues. In this paper, the work of [9, 10] are referred. Earlier work reported in [11] is extended which includes the sensor nodes coordination that utilizes an adaptive linear sensor node array (LSNA). Each sensor node is assumed with identified location and equipped with isotropic antennas which in random deployment. The normalized power gain characteristics derived in the case of the adaptive LSNA are compared with the conventional uniform linear array (ULA).

2. SYSTEM MODEL AND RADIATION PATTERN OF THE ANTENNA ARRAY

The geometrical configuration of the randomly distributed sensor nodes and the target point are illustrated in Fig. 1. All the sensor nodes are assumed to be located on the $x$-$y$ plane. Each sensor node is denoted in Cartesian coordinate $(x_k, y_k)$ while the location of the target point is given in spherical coordinates, $R_x(R, \phi_0, \theta_0)$. The angle $\phi \in [-\pi, \pi]$ represents the azimuth direction and $\theta \in [0, \pi]$ represents the elevation angle. In the system modeling, the following assumptions are made:

(i) Sensor nodes are plotted in random distribution inside the region of interest of $100 \text{m}^2$.

(ii) Each sensor node is modeled as isotropic antenna element and mutual coupling between nodes is excluded.

(iii) There is no multipath fading or shadowing.
After deployment, the sensor nodes intelligently organize themselves into clusters. Each cluster has a centre node (CN) designated as the head which manages and organizes a subset of its sensor nodes into a LSNA. A linear array of $q_k$ isotropic elements as shown in Fig. 2 is constructed as a ULA. The CN also acts as the centre of the ULA. If $d_k$ is the distance between the $k$th node and the reference node at the origin, then the signal $s(t)$ arrives $t_k$ seconds earlier at the $k$th element, with respect to the reference sensor node [9] as given by:

$$t_k = \frac{d_k \cos \theta_{ao}}{c} \quad (1)$$

where $c$ is the speed of light and $d_k$ is the distance of the $k$th element.

Each array element is weighted by a complex weight $w_k$

$$w_k = I_k e^{j\omega t_m \theta_{ao}} \quad (2)$$

for $k = 0, 1, 2, \ldots, K - 1, K$ which multiplies the incoming signal.

The amplitude of each element response, $I_k$, is assumed to be unity. The summation of all the elements’ weighted inputs equals the radiation pattern (the spatial response) of the array or the array factor [9], $F(\theta)$. By using Eq. (1) and the wave number $\beta = 2\pi/\lambda$, this is written as:

$$F(\theta) = \sum_{k=1}^{K} w_k^* e^{j\beta d_k \cos \theta} \quad (3)$$

The maximum value of $F(\theta)$ at $\theta = \theta_{ao}$ is the main lobe of the radiation pattern pointing towards $\theta_{ao}$. The normalized power gain $G$ is given by

$$G(\theta) = \frac{|F(\theta)|^2}{\max |F_{\theta a}(\theta)|^2} \quad (4)$$

3. NODE COORDINATION

Initially, 150 sensor nodes are randomly plotted. Each sensor node will communicate with nearby neighbor nodes which are located within the communication radius. The algorithm starts by selecting the CN which has the most neighbor nodes within its communication radius. Then, the active cluster is determined by referring to the CN as the centre of a cluster. A linear array of nodes is then constructed in the randomly deployed sensor nodes with internode spacing of $\lambda/2$. For case-study, a linear array of 9-nodes was constructed.

The development of the algorithm is aimed at determining the optimum sensor nodes coordination for beamforming. The radiation beampattern from the optimum LSNA has to be comparable to that of the ULA. Instead of exploiting all the sensor nodes in the active cluster, the algorithm is designed to choose only one set of sensor nodes in the linear node coordination that approximates the ULA. ULA is assumed with internode spacing of $\lambda/2$, isotropic antenna elements, and the CN represents the centre element as shown in Fig. 2.

A virtual line that passes through the CN is first constructed using the line equation

$$f(x) = m_2 x + m_1 \quad (5)$$
where $m_2$ is a virtual line slope and $m_1$ represents the offset of the origin. The CN is located at the centre point of the virtual line. By constructing the virtual line, selection of the sensor nodes is realizable. The ideal coordinate for the node’s location is then identified by referring to the virtual line to demonstrate the ULA.

$$q(x_{k+1}, y_{k+1}) - q(x_k, y_k) = \lambda/2$$

(6)

where $k = 1, 2, \ldots, 9$ $\equiv$ number of elements, and $q(x_k, y_k)$ is the coordinate of the $k$th element.

Fig. 3 shows the virtual line being constructed in MATLAB environment that passes through the CN.

Consequently, the algorithm intelligently optimizes the sensor node coordination in order to form an optimum LSNA. Two simulation scenarios in MATLAB environment are shown in Figs. 3 and 4. It is observed that from the random deployment of sensor nodes, the active cluster has been selected with reference to the chosen CN. The optimization of the LSNA has been successfully accomplished for 20 iterations. The process was repeated in different angles for optimum LSNA.

4. COMPARISON OF NODE COORDINATIONS

Performance comparisons of the optimized 9-element LSNA with 9-element conventional ULA are possible with the incorporation of beampattern analysis feature in the simulation environment. Figs. 3 and 4 show the first and second iterations of node coordination with different angles, while Figs. 5 and 6 illustrate the beampattern analysis of the node coordination, respectively.

From Figs. 5 and 6, it can be observed that the normalized array factor or normalized gain demonstrates maximum gain at the desired angle of 45°. It can be inferred that by using adaptive LSNA, the radiation power can be concentrated only to the desired angle or direction while suppressing the radiation powers at other angles. The optimized LSNA causes severe impact on the
increment of the sidelobe levels but only minimal reduction for the main lobe gain. However, by using Least Square (LS) method, the beampattern analysis of LSNA demonstrates excellent agreement with the performance of ULA. The maximum normalized power gain remains unchanged although in the presence of position errors in the LSNA coordination. In addition, the gain of the first sidelobe level also shows a promising performance and also only a slight decrements of the other lobes.

The simulated results also demonstrate the different effect on the beampattern performance with the alteration of the node coordination. Fig. 5 illustrates a wider 3-dB beamwidth compared to the 3-dB beamwidth of Fig. 6. The desired beampattern performance can be selected by using the beampattern analysis in order to meet the desired transmission signal.

5. CONCLUSION

The combination of the transmission of multiple sensor nodes is proven to provide greater transmission distances. The array geometry that has been considered is LSNA. The node coordination is optimized to identify the most excellent node coordination to participate in the LSNA. Simulation results illustrate that the construction of the adaptive-LSNA from random deployment offer superior performance to closely approximate conventional ULA.

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REFERENCES