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"Performance Evaluation & Application of Smart Antenna in Sensor Networks"

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Abstract

This research work provides a method for forming a communications link of Wireless Sensor Networks (WSN) by enabling each WSN to act as a smart antenna. Each WSN is simulated as a set of randomly placed sensor nodes within a planar area. The proposed method involves a searching WSN, a receiving WSN and a link budget for establishing the link. The searching WSN has the task of transmitting a search beam in order to find adjacent WSNs. We also demonstrate that for a given required gain level we can spatially thin the array without significant loss of gain or the effects of grating lobes. The receiving WSN uses a spread spectrum based space division multiple access (SDMA) receiver. This receiver is simulated to determine the direction of arrival from the searching WSN and to extract the location information from the searching WSN's signal with additive white Gaussian noise.

***KeyWords** - WSNs, OTH Network, Beamforming, DOA, SDMA Receiver, Message Extraction.*

1. Introduction

Wireless sensor networking is an emerging technology that has a wide range of potential applications. A wireless sensor node is a low cost, small, battery powered electronic device designed to monitor or measure a physical phenomenon of the environment around it, such as temperature, pressure, humidity, soil pH, vibration, motion, light, sound, radiation, and chemical presence. Wireless sensors are generally composed of a microprocessor, the appropriate sensor(s), a transceiver and a power source. Many different types of applications for wireless sensor networks exist, in both industry and the military world. Commercial applications of wireless sensor networks include industrial monitoring, building controls, security, traffic management, weather, wildlife tracking, and agricultural field temperature-sensing networks [1][2]. Military applications may include remote sensing of nuclear, biological or chemical (NBC) agents, motion, video, etc. It is assumed that the sensor nodes are deployed in hostile territory and therefore delivery of the sensors may be via an aerial vehicle (UAV).

In this work we seek to communicate not via a UAV, but by establishing links between already placed WSNs. In more general applications, a WSN need not be on the ground but can be attached to a building, bridge, structure or even a moving vehicle. The goal of this paper is to explore methods for forming communication links between adjacent WSNs. By establishing communication links between adjacent WSNs, we can form an extended network known as Over The Horizon (OTH) network. The general case is shown in Figure 1.

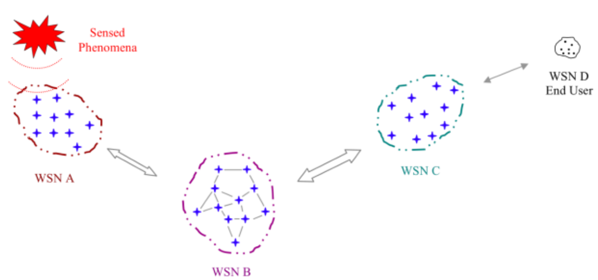

Fig. 1 Generalized OTH Network of WSN

Next we consider a tactical military example where we wish to link WSNs to form an OTH network. The goal is to connect the WSN A to B, B to C, etc. such that we eventually have a link from A to E. In previous work related to this scenario, each of the WSNs communicated directly to the UAV when it was available overhead [3].

This paper builds upon the concept of the random planar array of sensor nodes, but here the objective is to build an OTH network of WSNs. We also propose new

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ways for searching, tracking and establishing a link between adjacent WSNs. The communication links between adjacent WSNs are established by using beam searching and direction of arrival methods based upon spread spectrum techniques.

The rest of the paper is organized as follows: Section 2 summarizes related work. We will discuss the use of beam-forming as a method to search for adjacent WSNs in Section 3. Section 4 describes the link establishment process and the determination of the direction of arrival (DOA) using spread spectrum based space division multiple access (SDMA) methods. The performance of these techniques is given by simulation in section 5. In the end, conclusion and future work are given in section 6.

2. Related Work

The concept of beam forming using an array of randomly distributed sensor nodes has been explored previously in several works. Batson [4] studied wireless sensor networks as a means to collect signals intelligence by building adaptive arrays. Vincent [5] considered a similar problem to the one we explore in this thesis, namely that of a WSN deployed in a remote location that uses adaptive beamforming to communicate to an overhead UAV. Vincent also explored energy burden sharing across the sensor network, a concept that is conceptually useful to an over the horizon network. Chan [6] studied adaptive beamforming for direction of arrival calculation as well as the effects of position error and element failure on the beam of a random array of elements. Godara [7] Presents an extensive compilation of techniques for beamforming and direction of arrival estimation, as well as a comparison of the relative performance of each. While Hong, et al [8] use cooperative methods to establish a relay network of sensors, they use spatial diversity techniques rather than beamforming. In this paper, we propose a new ways for searching, tracking and establishing a link between adjacent WSNs.

3. Searching Wireless Sensor Networks

WSN has the task of transmitting a search beam in order to find adjacent WSNs. Like the rotating beam of a lighthouse, the WSN will steer its beam in a rotating manner around the horizon by using the local network of sensor nodes as an aperiodic antenna array.

3.1 Beam-forming of Randomly Placed Sensor Nodes

To describe how we will form a beam using a group of randomly placed sensor nodes. We assume that the sensor antenna elements are half wave dipoles oriented vertically to the plane. The far field pattern for an array of geometrically arranged antennas is calculated using pattern multiplication; that is, the far field radiation pattern $F(\theta)$ can be expressed as the product of the element pattern $E_O(\theta)$ and the array factor $AF(\theta)$ [9]:

$$F(\theta) = E_O(\theta) \times AF(\theta)$$

A characteristic of periodic arrays is revealed when the spacing between elements increases beyond a certain level, and energy from the array is directed into unintended directions. These unintended beams from the array essentially reduce the gain of the array along the desired direction by putting energy into unwanted directions. These unintended beams are called grating lobes and are the subject of the next section.

Grating lobes occur when element spacing is greater than one-half wavelength [9]. These lobes are often of equal intensity to the main lobe(s) of the array and are due to the periodicity of the element spacing. Grating lobes do not occur for arrays with spacing less than one-half wavelength; thus, nearly all periodic arrays conform to this spacing constraint [9].

3.2 Random Arrays

A random array is an array antenna whose elements are randomly placed along both the x and y-axes in a random planar array, i.e., the inter-element spacing is random along both the axes. Thus, for N total elements, the array factor becomes:

$$AF(\theta,\phi) = \sum_{n=0}^{N-1} A_n e^{jk[(x_n \sin\theta\cos\phi + \beta_x) + (y_n \sin\theta\sin\phi + \beta_y)]}$$

Substituting

$$\beta_x = -kx_n \sin\theta_o \cos\phi_o \text{ and } \beta_y = -ky_n \sin\theta_o \sin\phi_o$$

into Equation gives the array factor for the *N* element random planar array:

$$AF(\theta,\phi) = \sum_{n=0}^{N-1} A_n e^{jk[(x_n \sin\theta\cos\phi - x_n \sin\theta_o \cos\phi_o) + (y_n \sin\theta\sin\phi - y_n \sin\theta_o \sin\phi_o)]}$$

Where (θ_O, φ_O) determine the beam pointing angles. This equation is used to determine the array factor in all subsequent calculations involving random planar arrays. Random arrays exhibit some special characteristics that differentiate them from periodic arrays. It should be no surprise then that grating lobes, an artifact of the periodicity of uniform arrays, are significantly reduced in random arrays because of the random nature of the elements [10].

4. Direction of Arrival

When the receiving WSN detects a signal from the searching WSN, it needs to know the relative geometries of the two WSNS in order to form its array and then send a reply. The location information of the sending WSN is contained within the message signal transmitted, but the direction of arrival (DOA) must be calculated. A spread spectrum space division multiple access technique is introduced and demonstrated first with a linear array, and then applied to the random planar array. The strengths of this technique as well as the importance of the spread spectrum pseudorandom noise codes are explained.

4.1 Requirement for a Blind DOA Algorithm

DOA determination methods that do not use prior knowledge of signal direction or some sort of reference signal to form an initial estimate for the DOA are termed blind DOA methods. A new method based upon spread spectrum techniques for space division multiple access (SDMA) applications is suitable for random arrays and has the capability for blind DOA determination, we chose this method for the receiving array.

4.2 Space Division Multiple Access Receiver

Analogous to the code division multiple access (CDMA) receiver, this space division multiple access receiver (SDMA) spatially separates received signals using DSSS techniques. The method involves chipping the phase of the received signals at each array element with individual spreading sequences. In computer memory identically chipped virtual signals are generated from a virtual receiver array for *I expected* directions of arrival.

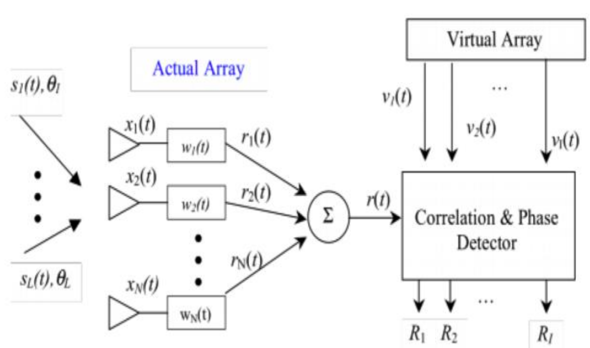


Fig. 2: SDMA Receiver

The received signals are then summed and a quadrature correlation is performed between the received signal and each of the *I expected* DOA virtual signals. Correlation values (R_i) exceeding a threshold are identified as signals received from an expected DOAi. From the phase of the correlation R_i, the message signal information may be extracted. Interfering signals are not well correlated and thus minimized [11].

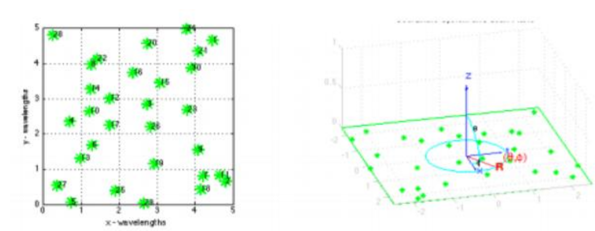
5. MATLAB Simulation Results

We apply the SDMA technique to the random planar array of dipoles to determine the DOA of a test signal and compare the gain pattern from the SDMA technique to that of the array as calculated in section 2. Having found the DOA, we simulate the decoding of a sample message representing bits of a data stream from the searching WSN.

5.1. DOA Determination

We now apply the SDMA technique to a planar array of randomly placed sensors. Figure 3(a) depicts an overhead view of the elements of a 5λ x 5λ sensor WSN containing 30 elements, randomly distributed with the array scanning the x-y plane. Figure 3(b) depicts the simulated test signal incident from θ = 90° and φ = 30°. In this diagram R (θ, φ) is shown to establish the coordinate system and indicates the direction of incidence of the test signal.

With the geometry shown in Figure 3, the gain pattern of the random planar array was calculated using Equations (2) and (3) and compared to the SDMA gain pattern. In Figure 4, the green line shows the gain pattern of the random planar array with the incident test signal; it is the signal the SDMA technique must locate. The SDMA gain pattern is presented in blue and shows excellent agreement with the calculated gain pattern.



(A) (B)

Fig. 3 Thirty Element Random Planar Array Realization and Coordinate System

The 30 elements produce a peak gain of 17.8 dB, the beamwidth is 8 degrees and the highest side lobe rises to 9.3 dB below the peak. These results validate the

SDMA technique as a method for blindly determining the DOA when applied to the random planar array. It shows excellent agreement between the theoretical array patterns and those produced by MATLAB. This will allow the receiving WSN to almost instantaneously determine the DOA of the searching WSN. Having determined the DOA of the searching WSN, the task of the receiving WSN is to extract the location information from the message signal sent by the searching WSN.

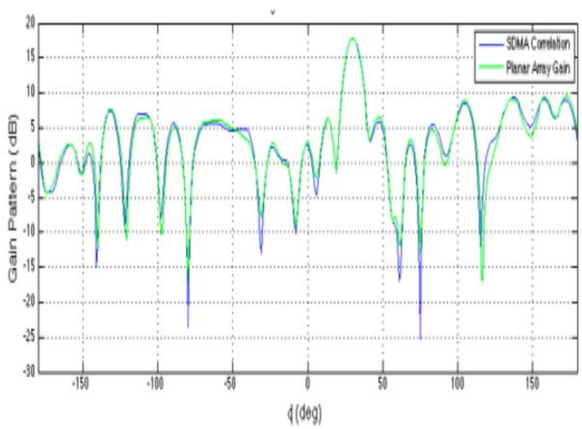


Fig 4. Gain Pattern of 30 elements Random Planar Array Steered to 30^o with SDMA Estimation of incident Pattern Signal

5.2. Message Extraction

One of the primary goals of the receiving array is to extract a message from the transmitted signal containing the location of the searching WSN. In order to demonstrate this, we will simulate the baseband message signal as a bit sequence and include it in the signal incident from 30°. The goal is to transmit an 8 bit sequence (0 1 1 0 1 0 1 1) mapped to (1 -1 -1 1 -1 1 -1 -1) as the sample message. The signal phase ζ(t) was generated with additive white Gaussian noise (AWGN) with a 20 dB signal to noise ratio to simulate channel interference. Here MATLAB measures the power in ζ(t) and adds AWGN at 20 dB. The signal to noise ratio is the ratio of the power in the signal ζ (t) to the power in the AWGN.

The results of this simulation are shown in Figure 5. We see in blue, the instantaneous baseband signal ζ(t) with AWGN. Green is the phase term $_{(i=30)}$ of thecorrelation sequence R_i at the incidence angle θ =30^0.The time sample of the received signals is of length T and shown in red. We see that the signal bit sequence can be accurately extracted from the recovered estimate of the phase. In order to test the strength of the SDMA technique, we increased the noise level such that the SNR was now −5 dB. Figure 6 shows the received baseband test signal in blue encoding the same bit sequence at the higher noise level. The recovered signal is shown in green. Although the noise level appears very high, the SDMA technique is still able to extract the data in the incident signal. This suggests that the receiving WSN is capable of extracting the message bits under high noise conditions

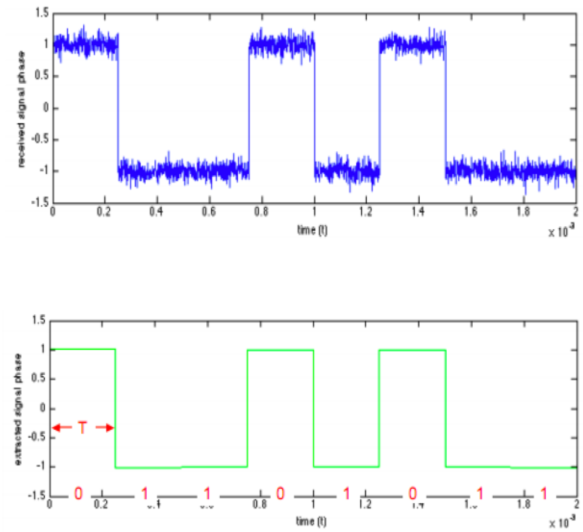


Fig 5. SDMA Message Extraction of Sequence [01101011] from noisy baseband Signal, SNR = 20dB.

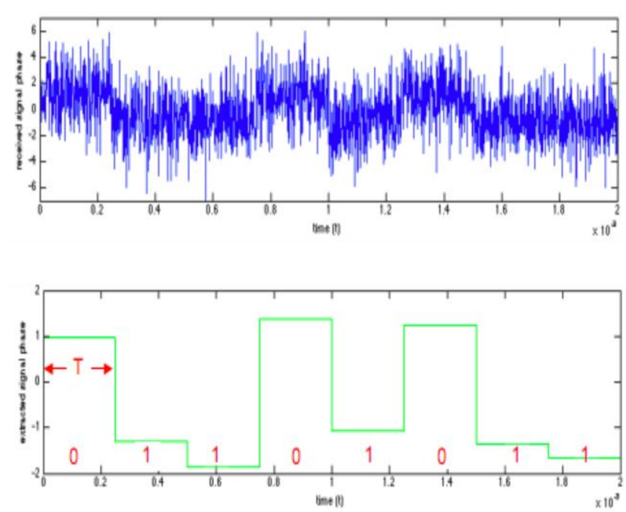


Fig 6. SDMA Message Extraction of sequence [01101011] from noisy Baseband Signal. SNR = -5 dB

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6. Conclusion

In this thesis we explored methods for forming an Over The Horizon (OTH) communications link of Wireless Sensor Networks (WSNs) by enabling each WSN to act as a smart antenna array. Each WSN was modeled as a uniformly distributed random array of sensors nodes. An element random planar array, comparable to a 36 element periodic planar array of similar size, was simulated to demonstrate the search capability. Methods for establishing the OTH communications link via beam forming and direct sequence spread spectrum Space Division Multiple Access (SDMA) were presented and modeled using MATLAB. Methods for forming a search beam for a transmitting WSN and determining the direction of arrival of the received beam for a receiving WSN were presented. Using a random planar array, we validated the SDMA method by determining the DOA of an incident test signal and then extracting a message data stream from this signal in a noisy channel. From the DOA and the location information within the arriving signal, the WSN has sufficient knowledge to respond to the query of the searching WSN.

7. References:

[1] SmartBridges Inc, Customer Success Stories website, “Wireless Farm Area Network for Rice Field Research,” April2008, http://www.smartbridges.com/css/articles.asp?id=491.

[2] A. Magnani and K.K. Leung, “Self-Organized, Scalable GPS-Free Localization of Wireless Sensors”, in Wireless Communications and Networking Conference, 2007.WCNC 2007. IEEE, Kowloon, Hong Kong, 11-15 March 2007 pp 3798-3803.

[3] P. Vincent, “Energy conservation in wireless sensor networks”, PhD dissertation, Naval Postgraduate School, Monterey, California, USA, June 2007.

[4] M. Batson, Enhanced radio frequency (RF) collection with distributed wireless sensor networks,” PhD dissertation, Naval Postgraduate School, Monterey, California, USA, June 2007.

[5] P. Vincent, “Energy conservation in wireless sensor networks”, PhD dissertation, Naval Postgraduate School, Monterey, California, USA, June 2007.

[6] C. W. Chan, “Distributed beamforming in wireless sensor networks”, Masters thesis, Naval Postgraduate School, Monterey, California, USA, December 2004.

[7] L. C. Godara, “Application of antenna arrays to mobile communications, part II: beam-forming and direction-of-arrival considerations,” in Proceedings of the IEEE, Vol. 85, No. 8, pp 1195-1245, August 1997.

[8] Y.-W. Hong, W.J. Huang, F.-H. Chiu, and C.-C. Jay Kuo, “Cooperative Communications in Resource-Constrained Wireless Networks,” IEEE Signal Processing Magazine, Vol. 24, Issue 3, pp 47-57, May 2007.

[9]W. Stutzman & G. Thiele, Antenna Theory and Design, John Wiley & Sons, New York, 1981.

[10] B. D. Steinberg, Principles of Aperture and Array System Design, including Random and Adaptive Arrays, John Wiley & Sons, New York, 1976, p 77.

[11] F. Gross, Smart Antennas, McGraw Hill, New York, 2005, p 92.