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Performance of Smart Antennas in Wireless Sensor Networks

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ABSTRACT

Smart Antennas provide angle-of-arrival information, which can be used for localization and efficient routing of information in wireless sensor networks (WSN). The method of designing a communications link between different nodes of a Wireless Sensor Networks (WSNs) by electronically steering the beam using smart antenna is presented. A brief design details and beam pattern measurements of a prototype smart antenna array operating in 2.4 GHz band is evaluated which is highly directional & capable of beamforming and provide benefits such as the extended communication ranges, spatial reuse of the spectrum , and reduced interference patterns, enabling higher network performance compared to omnidirectional antennas. The proposed method is studied on searching Node of a WSN, as well as receiving node of a WSN. The searching WSN has the task of transmitting a search beam in order to find adjacent WSNs. This system is simulated to determine the direction of arrival from the nodes of WSN and deriving the location information from the signal, using the direction or arrival (DOA) estimation technique.

Keywords

Smart Antenna, Adaptive Processor, DOA Estimation, MUSIC Algorithm, AOA, BER Improvement.

1. INTRODUCTION

In this paper we consider the use of smart antenna systems [1, 2] in order to achieve reliable and efficient data delivery in wireless sensor networks [3, 4]. Smart antenna consists of multiple antenna elements with feedback control and an algorithm which provides the optimum performance of the array [5]. MUSIC algorithm [6, 7] is implemented in the array processor for deriving the angle of arrival of the signal & simultaneously location of the WSN nodes are identified for efficient delivery of data packets [8, 9, 10]. Subsequently the pattern of the antenna is optimized by using any one of the adaptation algorithm available viz. LMS or D3LS [11].

2. SMART ANTENNAS IN SENSOR NETWORKS

A Wireless Sensor Network (WSN) consists of a large number of small sensor nodes with sensing, data processing, and communication capabilities able to realize a distributed and remote control of the environment [3, 9]. Usually the network nodes are randomly deployed therefore the whole wireless architecture should be characterized by a highly dynamic and reconfigurable topology with self-organizing capabilities to guarantee an energy efficient transmission of the information on the scenario under test. In this context, the adoption of a smart system at the communication interface is certainly an optimal solution not only to reduce the RF-energy consumption, but also in order to maximize the efficiency of the data exchange among the network nodes. A typical adaptive antenna system block diagram is shown in the Figure 1. The adaptive antenna generally has degrees of freedom in the form of amplitude and phase or time delay weighting of multiple channels to adjust its radiation pattern [5, 8].

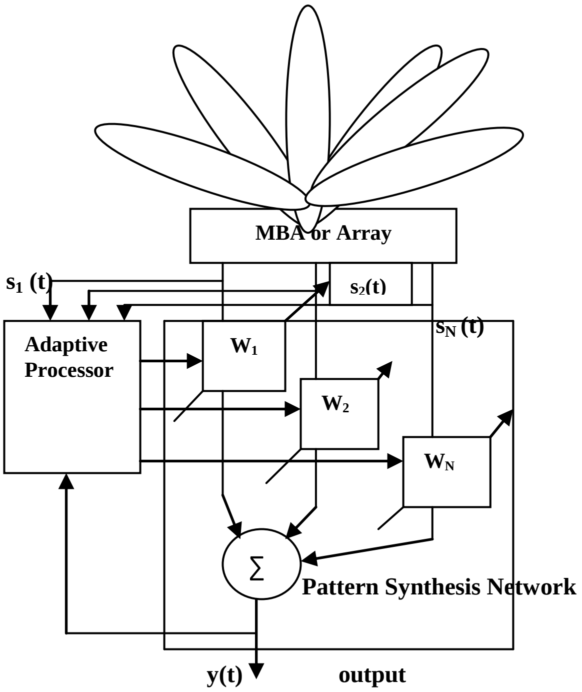

Figure 1: Adaptive Array Antenna with feedback system and Complex Weighting

3. MUSIC ALGORITHM FOR ADAPTIVE PROCESSOR

DOA estimation is conducted at various angles by using MUSIC algorithm [6]. The DOA in 30°~90° range is estimated approximately within ±5° error. It is found MUSIC algorithm requires very precise and accurate array calibration and consideration of sub array concept. The Correlation matrix of sensor observations $X(t)$ is calculated initially.

$$R = X(t).X(t)^H \qquad \textbf{(1)}$$

Here 'H' represents a conjugate transpose. In practice only a sample covariance matrix is available i.e., an estimate of R based on a finite number (P) of data samples or snap sorts.

$$\hat{R} = \frac{1}{P}\sum_{j=1}^{P} X(t_j).X(t_j)^H \qquad \textbf{(2)}$$

Then need to obtain the Eigen values decomposition

$$\hat{R} = V\Lambda V^H \text{; where } V = [v_1,....,v_N];$$

$$\& \ \Lambda = diag[y_1,....,y_N];$$

where v_k is an eigenvector (N- dimensional column vector) and y_k is the Eigen value of v_k sorted as $y_1 \geq .... \geq y_k$. The K points where the function

$$U(\theta) = \sum_{k=K+1}^{N} \left| v_k{}^H a(\theta) \right|^2 \qquad \textbf{(3)}$$

approaches zero corresponds to the direction $\theta_1,....,\theta_k$ of the signal sources. If the number of K sources is smaller than the number of N of sensors, then the entire signal components are represented in the signal subspace spanned by the first K Eigen vectors $v_1,.....,v_N$ and the remaining N-K Eigen vectors, $v_{K+1},....,v_N$ represents the noise subspace. The signal subspace and the noise subspace are orthogonal to each other since they are spanned by different Eigen vectors. The subspace spanned by the K steering vectors $a(\theta_1),....,a(\theta_k)$ is also the signal subspace. When θ coincides with one of the source directions $\theta_1,.....,\theta_K$ the steering vector $a(\theta)$ and the noise subspace $v_{K+1},.......,v_N$ are orthogonal and therefore $U(\theta)$ approached zero. This is why source direction can be estimated using $U(\theta)$. For the noise subspace to exist, the number of N of sensors should be larger than the number K of sources. Thus the sub array based MUSIC algorithm is applicable for mixtures of upto N-1 signals. Figure 2 shows the MUSIC Spectrum, that array processor has identified 3 genuine sources of signal transmitted from three slave nodes spatially positioned at 30°, 60°& 65°.

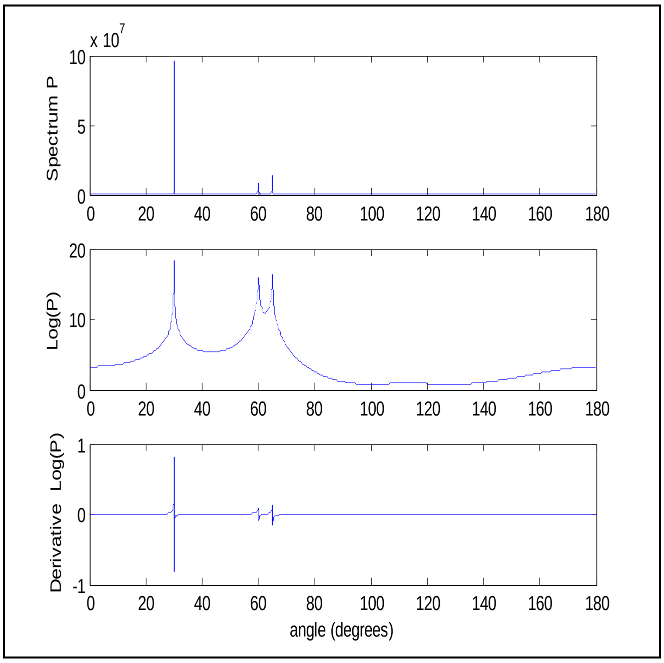

Figure 2: MUSIC Spectrum for 3 Signal Sources with array spacing .5λ

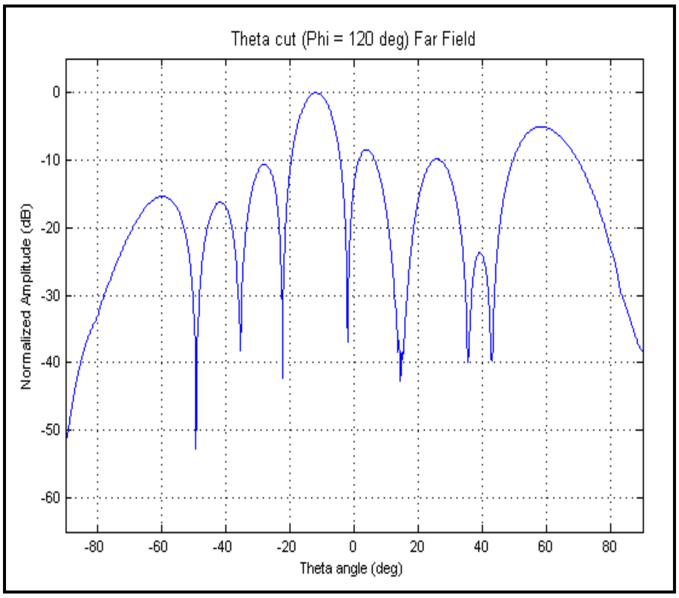

Figure 3: Beam pattern for 4×4 Planar Adaptive Array steering in multiple direction

4. SIMULATION RESULTS

The antenna array is uniformly distributed over a planar area. The elements are *z* directed with fixed element spacing .5λ. The array size is characterized in terms of wavelengths and the number of elements *N*, which represents the total number of elements. The periodic planar arrays modeled as the elements along each axis, e.g., $N_x = 4$ and $N_y = 4$ for a total of 16 elements. Here, we simply use N = 16 to indicate that there are 16 elements within the array. In the Figure 3 normalized amplitude pattern of the 4×4 planar Adaptive Array installed at Master node is shown. Master node is communicating with multiple spatially distributed slave nodes over wide angular span of -60°, -36°,-28°, -12°, 4°, 24°, 55°. Figure 5 shows normalized far field pattern in 3D space where bright red is indicating maximum gain & lower gain is shown in purple and blue. Figure 4 shows the algorithm used for calculating angle of arrival of the signal generated from different nodes is converged with timing iterations, means design is stable. The maximum gain of a planar Adaptive array is affected by increasing the number of elements & it is observed that the gain of an N element planar array approximates that of an N element linear array and the average side lobe level is 1/N below the maximum gain and the peak side lobe level is not more than 10 dB above the average side lobe level. This simulation will validate these observations for the random smart array. In order to maintain link among the WSNs, desire is to control the width, gain and direction of the array beam. Figure 5 has shown that multiple beam can be steered in an arbitrary direction depending upon AOA. To achieve a given beam width, we choose a physical size, likely a sub-section of the WSN under consideration. The physical size of the array controls the HPBW. Figure 6 shows results on throughput, calculated with the system presented above for both an Omni directional antenna and smart antenna. Smart beamforming model can increase the throughput substantially compared to the Omni-directional antenna system for WSN.

5. RF PERFORMANCE MEASUREMENT

Adaptive antenna array have control over the channel capacity, by increasing the number of elements employed in the array the channel capacity can be improved as shown in Figure 7. It is very clear that channel capacity is increasing sharply while the numbers of array elements are increasing. Alternately, for a given required gain level we can thin the array (or reduce density) without significant loss of gain or the effects of grating lobes. It does not matter which particular sensor nodes within the WSN are used as long as, on average, they are distributed within the physical area chosen. From the DOA and the range information encoded within the arriving signal, the WSN has sufficient knowledge to build its reply to the query of the searching WSN. In this context Sensors determine their neighborhood relationships and also determine the senders and the receivers of the data traffic. Then, neighborhood relationships are exchanged between neighbor sensors. Nodes receive priority levels according to their number of nodes. A location table is maintained in each node which includes the priority information and the sender-receiver relationships. The time schedules are negotiated among the neighbors according to the priority levels.

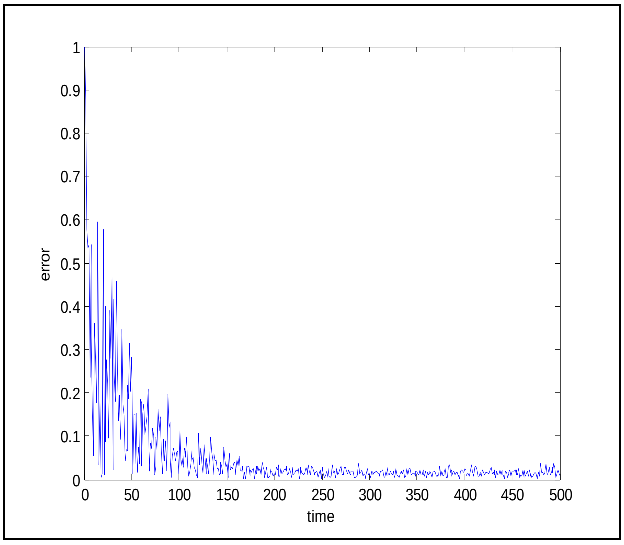

Figure 4: Magnitude of System Error with time

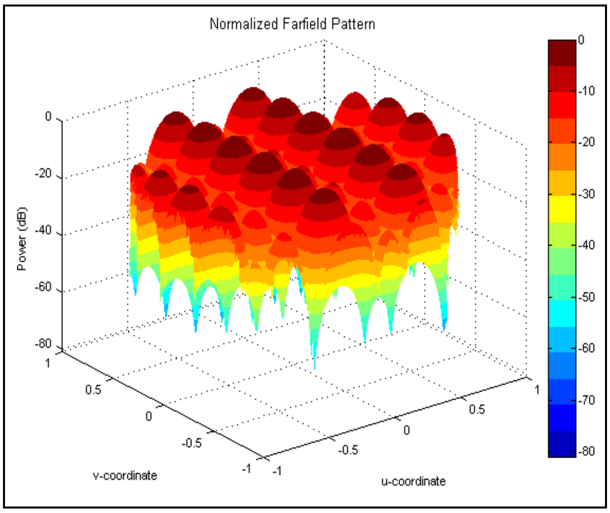

Figure 5: 3D Radiation Pattern for Adaptive Array

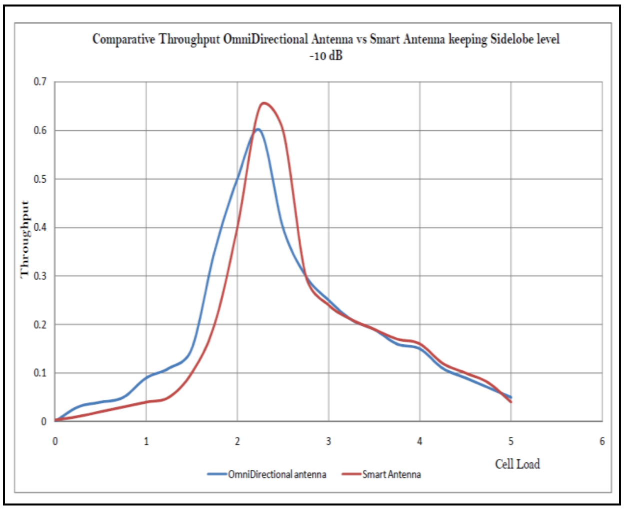

Figure 6: Simulated throughput for Omnidirectional Antenna vs. Smart Array with 16 Elements (SLL - 10 dB)

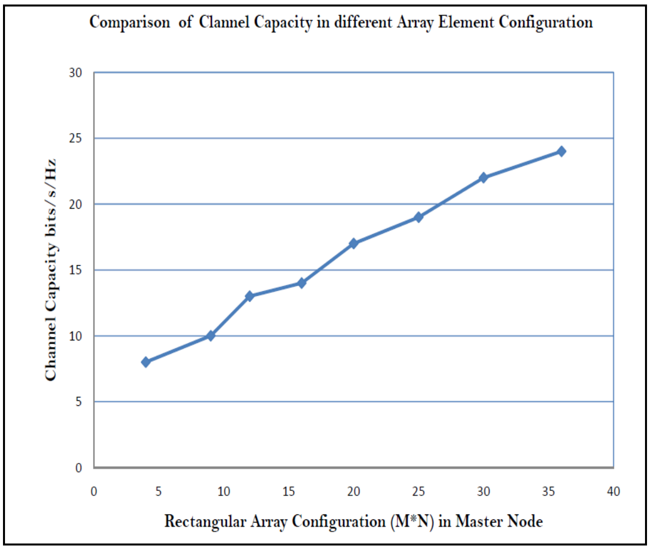

Figure 7: Comparison of Channel Capacity in different array Configuration

6. CONCLUSION

In this paper successful application of smart antenna to wireless sensor network is presented. Simulation result has revealed significant improvement in throughput if smart antennas are employed instead of an omnidirectional antenna. Two different scenarios that can affect the performance of the smart antenna system are examined. In the first case the effective transmit range of the transmitter is kept constant by imposing a limit on the maximum radiated power allowing both Omni and smart antenna system & secondly the maximum power that should be supplied to the antenna section kept defined and this allowed the smart antenna section to vary it’s radiated power depending on the gain in a given direction. The performance of the smart antenna system was different for these two scenarios. For constant radiated power smart antenna system consistently performed better that the omnidirectional antenna system. The reason is even though both Omni and smart antenna had the same range the smart antenna was able to use space division multiplexing more efficiently with its directed beam patterns. In wireless sensor networks, the sensor nodes are often randomly situated, and each node is likely to be equipped with a single antenna. If these sensor nodes are able to synchronize, it is possible to form beam by considering sensor nodes as a random array of antennas. Using probabilistic arguments, it can be shown that random arrays formed by dispersive sensors can shape nice beam patterns with a sharp main lobe with low side lobe levels. The smart antenna is capable of suppressing a 12 dB stronger interfering signal located 10 degrees in angle from the desired signal source and gives better BER. In a SDMA system the near-far effect and the fading margin imposes additional constraints on the minimum angle allowed between two wireless sensor nodes.

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