AIS Algorithm for Smart Antenna Application in WLAN

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Abstract. Increasing numbers of wireless local area networks (WLAN) replacing wired networks have an impact on wireless network systems, causing issues such as interference. The smart antenna system is a method to overcome interference issues in WLANs. This paper proposes an artificial immune system (AIS) for a switch beam smart antenna system. A directional antenna is introduced to aim the beam at the desired user. The antenna consists of 8 directional antennas, each of which covers 45 degrees, thus creating an omni-directional configuration of which the beams cover 360 degrees. To control the beam switching, an inexpensive PIC 16F877 microchip was used. An AIS algorithm was implemented in the microcontroller, which uses the received radio signal strength of the mobile device as reference. This is compared for each of the eight beams, after which the AIS algorithm selects the strongest signal received by the system and the microcontroller will then lock to the desired beam. In the experiment a frequency of 2.4 GHz (ISM band) was used for transmitting and receiving. A test of the system was conducted in an outdoor environment. The results show that the switch beam smart antenna worked fine based on locating the mobile device.

Keywords: *smart antenna; switch beam; AIS; microcontroller; WLAN.*

1 Introduction

Algorithms are well known in computer programming. Essentially, they are a method for computers to process data. Programming or computation is identical to executing algorithms containing detailed and specific instructions. Thus, an algorithm can be considered to be any sequence of operations in data processing. Algorithms are a part of signal processing in smart antenna systems. The selection of the algorithm determines the accuracy in determining the angle

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of arrival (AoA) – also known as direction of arrival – of the receipt signal on the basis of which beam switching takes place [1]-[3]. Recently, researchers have proposed smart antenna system algorithms such as LMS (least mean square), MUSIC (multiple signal classification), ESPRIT (estimation of signal parameters via rotational invariance technique), or a combination thereof [4]-[5]. Another technique is the use of a neural network (NN) algorithm to determine the AoA, as reported in [6].

A smart antenna is a system consisting of a number of single antennas that form an array system, with digital signal processing that is capable of transmitting and receiving in an adaptive and spatially sensitive manner [7]-[10]. Each antenna has an individual beam area based on the antenna design and radiation pattern. The array of antennas increases the covered area to 360 degrees. There are two common types of smart antenna systems, namely switch beam systems and adaptive array systems. A switch beam smart antenna system requires a simple processing system and algorithm in order to switch the beam to the desired user, whereas an adaptive array smart antenna system requires more intelligent and complex data processing, which makes adaptive array systems more accurate and efficient compared to switch beam systems.

Various researches on smart antenna systems have been done. For the switch beam smart antenna system a technique has been explored that involves the reconfiguration of a single antenna and the application of a beam forming concept, as reported in [6],[11]-[13]. New switch beam methods based on algorithms and simulations are reported in [14]-[17]. Referring to the previous studies, the researchers have mostly focused on the common configuration of a single antenna for beam forming and the application of a beam forming concept for the switch beam system. Others were concerned with the implementation of a simulation of smart antennas and the application of an algorithm for intelligent and smooth beam switching. In this paper, we propose and explore the applicability of an AIS algorithm to the switch beam smart antenna system, where a negative selection algorithm was chosen and adopted to arrive at a signal processing algorithm for selecting the beam direction. We also explored an alternative solution, i.e. an inexpensive switching system consisting of a PIC 16F877 microcontroller to direct the beam at the desired mobile device.

2 Artificial Immune System

An artificial immune system (AIS) algorithm is an adaptive system, inspired by theoretical immunology and observed immune functions, principles and models, which are applied to problem solving [18]. The field of artificial immune systems is concerned with abstracting the structure and function of immune systems to computational systems and investigating the application of such systems towards solving computational problems from mathematics, engineering and information technology. AIS is a sub-field of biologically-inspired computing and natural computation, with interest in machine learning and belonging to the broader field of artificial intelligence [19]. Figure 1 shows the basic concept of a biological immune system.

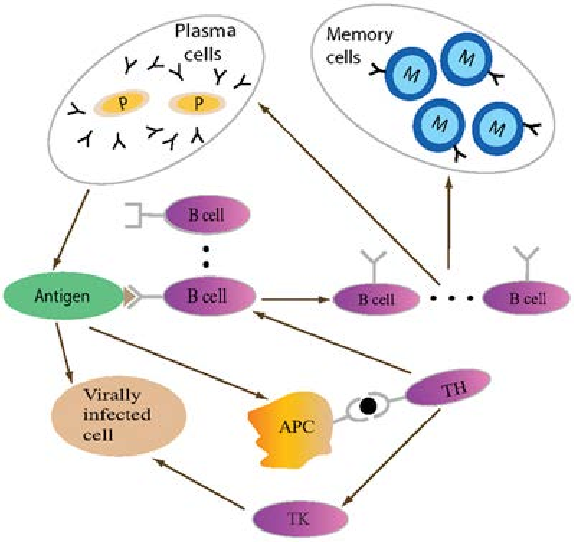
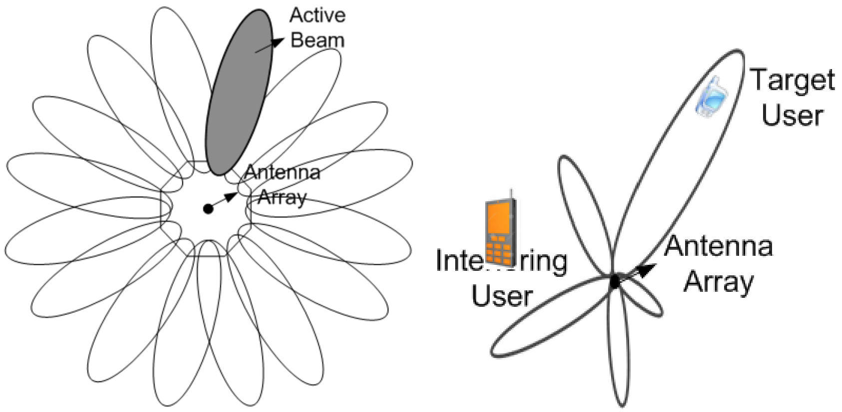


Figure 1 Basic concept of biological immune system.

3 Switch Beam Smart Antenna

A smart antenna system is an antenna array with a control system and digital signal processing system for advanced and intelligent control. It is used in wireless communications for locating mobile devices that are capable of directing their beam radiation in a particular direction. Nowadays, smart antenna technology with improved design contributes significantly to solutions for overcoming issues such as interference and for improving system capacity and efficiency. In this technology, the signal of a mobile device is received by the base station from the direction of the particular area where the mobile device is located. This method of transmission and reception is called beam forming, which is made possible through smart (advanced) signal processing at the baseband.

As mentioned before, there are two types of smart antenna systems commonly used, i.e. switch beam and adaptive array (more intelligent) systems. Switch beam or lobe switching systems comprise only of a basic switching function between the separate directive antennas or predefined beams of an array; the setting that gives the best performance is selected. An adaptive array system is an antenna system complete with a direction of arrival signal algorithm for determining the direction towards interference sources on the basis of which the radiation pattern can be adjusted to null out the interferers. Figure 2 shows the basic concepts of both smart antenna systems. Figure 2(a) shows an antenna consisting of multiple fixed beams that can be switched to any particular beam as controlled by the system, while Figure 2(b) shows an adaptive array antenna, which is a more intelligent system. Both systems have the same objective, which is to forward the antenna beam to one specific user, but adaptive array is a more efficient and effective system because it can suppress unwanted beams.



(a) (b)

Figure 2 Basic concept of smart antennas: (a) switch beam (b) adaptive array.

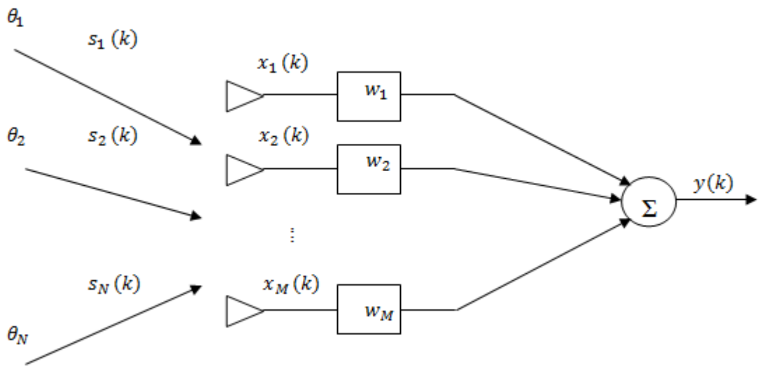


Figure 3 M-number array antennas with signal arrivals.

In a smart antenna system, the angle of arrival is one of the factors that determine the precise provenance of the receipt signal by the mobile station. A few techniques and algorithms exist to calculate and estimate the angle of arrival of a signal coming from a mobile device. Figure 3 shows a signal arriving from N directions, with N angles of arrival, which is received by an antenna array consisting of M elements with M potential weights. Every received signal of x(M)(k), includes additive, zero mean and Gaussian noise. Time *k* is the represented time sample. Thus, a summary of antenna array output y(k) can be written as follows:

$$y\,(k) = w^{-T}.\ \bar{x}(k) \tag{1}$$

where,

$$\bar{x}(k) = \ [\bar{a}(\theta_1)\ \ \bar{a}(\theta_2)\ \ .\ .\ .\ \ \bar{a}(\theta_N)]\,.\begin{bmatrix} s_1\,(k) \\ s_2\,(k) \\ . \\ . \\ s_N\,(k) \end{bmatrix} + \bar{n}(k)$$

$$= \bar{A}\,.\bar{s}(k) + \ \bar{n}(k) \tag{2}$$

and

$\bar{w}\ =\ [\,w_1\ \ w_2\ \ .\ .\ .\ \ w_M]^{\,T}$ = weight of array antenna
$\bar{s}(k)$ = vector of incident complex monochromatic signal at time k
$\bar{n}(k)\ =$ noise vector at each array element m, zero mean, variance $\sigma_n{}^2$
$\bar{a}(\theta_i)$ = M-element array steering vector for the θ_i direction of arrival
$\bar{A} = \ [\bar{a}(\theta_1)\ \ \bar{a}(\theta_2)\ \ .\ .\ .\ \ \bar{a}(\theta_N)]\ M\ X\ D$ matrix of steering vector $\bar{a}(\theta_i)$

The numbers of radiation patterns of a typical antenna array can be changed or it can be designed with a determined number of antennas installed. Higher numbers of array elements mean a narrower beam radiation pattern and complex signal processing is required because more elements of the antenna beam need to be calculated. Similar to changes in the relative phase excitation, the orientation of the radiation pattern will change. Each of the N complex signals arrives from various angles θ_i and is intercepted by M antenna elements, where the number of arriving signals N is normally smaller than the number of array antennas M. Eq. (1) represents a summary of the signals arriving from M elements of the antenna and Eq. (2) represents the number of $\bar{x}(k)$ antenna elements, where the vector signal arrives at time *k* from M angles of arrival. The steering vector contains the responses of all elements of the antenna array to a narrow-band source of power. Because there is a difference in direction between the responses of each of the array antennas, the steering vector is associated with any directional source [8].

The proposed switch beam smart antenna consists of eight elements (octagonal structure). These elements create an omni-directional form, where each element covers 45 degrees. Figure 4 shows the 8-element omni-directional antenna that covers 360 degrees. For each element the desired signal arrives from angle θ_1 and interference signals arrive from angles θ_2 to θ_8. Controlled by a simple switching system, the antenna will steer a beam to the desired particular user at the angle of the strongest received signal.

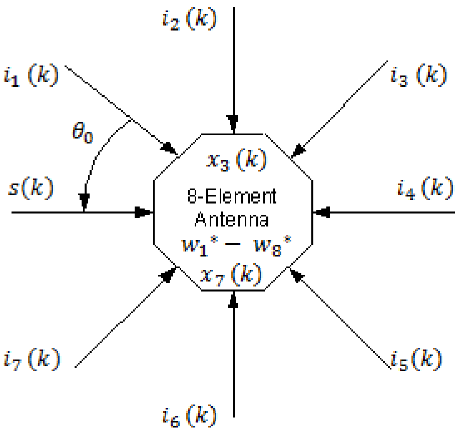


Figure 4 Proposed 8-element switch beam smart antenna.

As shown in Figure 4, the desired signal arrival is $s(k)$ to the first element of the array antenna $x_1\,(k)$ with an angle of θ_0, while the number of interference signals is $i_1\,(k)$ – $i_7\,(k)$. For the 8 elements of the array antenna, from $w_1{}^* - w_8{}^*$, with 8 potential weights, the array output $y(k)$ can be calculated as:

$$y\,(k) = w^{-H}.\ \bar{x}(k) \qquad (3)$$

where,

$$\bar{x}(k) = \ \bar{a}_0\, s(k) + [\bar{a}_1\ + \bar{a}_2\ + \bar{a}_3\ +\ \bar{a}_4\ +\ \bar{a}_5\ + \bar{a}_6\ + \bar{a}_7\,] \begin{bmatrix} i_1\,(k) \\ i_2\,(k) \\ i_3(k) \\ i_4\,(k) \\ i_5(k) \\ i_6\,(k) \\ i_7\,(k) \end{bmatrix} + \bar{n}(k) \qquad (4)$$

$$= \bar{x}_s\,(k)\ + \bar{x}_i\,(k) + \ \bar{n}(k)$$

and

$\overline{w}$ = $[w_1\ w_2\ w_3\ w_4\ w_5\ w_6\ w_7\ w_8]^T$
= weight of array antenna
$\bar{x}_s(k)$ = desired signal vector arrival
$\bar{x}_i(k)$ = signal vector interference
$\bar{n}(k)$ = zero mean Gaussian noise for each antenna element
$\bar{a}_i$ = M-element of antenna array steering vector for the θ_i direction of arrival

The most important question when determining multiple signals or multiple objects from a mobile device using the AIS algorithm is which criteria to use in order to verify what the true signal is from the device. Let's say the mobile device's signal comes written as:

$i_1(k), i_2(k), i_3(k)$ ………. $i_n(k)$, where n is number of signals in this case.

The decision vector of the incoming signal can be stated as

$$x = [x_1(k), x_2(k), x_3(k), \ldots x_s(k)] \tag{5}$$

where s is the number of vector signal variables that are sought. The AIS algorithm imposes self and non-self sets on the decision

$$g_i(x) <= 0,\ i = 1, .., m;\ \ h_i(x) = 0,\ i = 1, ..., p \tag{6}$$

m is the number of non-self and p is the number of self. It is important to ensure that $p < n$, else it will be difficult to find the correct arrival signal from the mobile device or object. Two parameters are defined for signal arrival:

n – dimensional space of solutions, where each dimension is assigned to each element of the x vector.
k – dimensional space of fitness values, where each dimension is assigned to one of the objects.

The final decision to choose the correct arriving signal from multiple objects is to create a multi-signal environment using a learning process and the experience of the decision signal received by the base station, after which the true signal can be determined as written in Eqs. (7), where:

Eqs. (3) and (4) above can be rewritten to get array output of signal arrival on smart antenna system $y(k)$ as:

$$\begin{aligned} y(k) &= w^{-H}.\ [\bar{x}_s(k) + \bar{x}_i(k) + \bar{n}(k)] \\ &= w^{-H}.\ [\bar{x}_s(k) + \bar{u}(k)] \end{aligned} \tag{7}$$

where,

$\bar{u}(k) = \bar{x}_i(k) + \bar{n}(k)$ = undesired signal arrival

4 Antenna Design and Prototype

The design of the switch beam smart antenna starts with designing each single element of the array antenna. The proposed frequency band of this antenna is 2.4 GHz (ISM band), similar to the transmitter and receiver frequency used by the system. The basic design of the single array antenna is a microstrip [20] using inexpensive materials available in the market. The proposed antenna is fabricated using FR4 material with a relative permittivity of ε_r = 4:7, height h = 1.6 mm and tan δ = 0.019. Figure 5 shows a single fabricated element of the array antenna with directional direction and a beam width of 50 degrees.

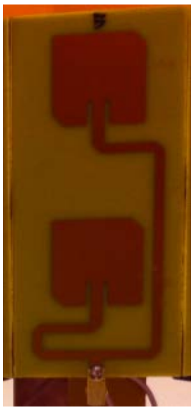
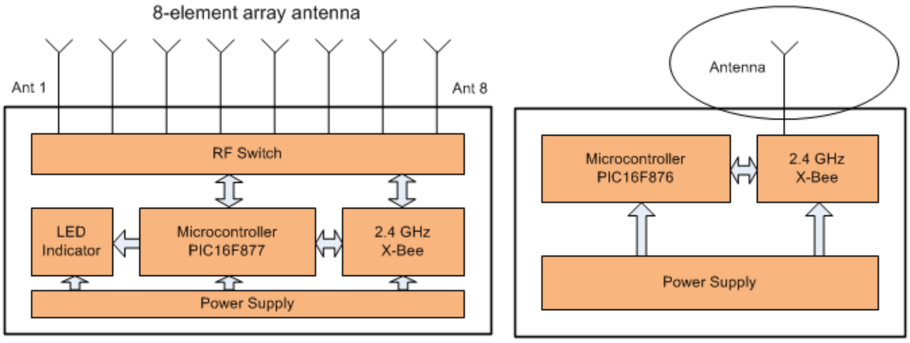


Figure 5 Single element of array antenna.

As mentioned previously, the proposed switch beam smart antenna has an octagonal configuration which consists of 8 single antennas. Figure 6 shows a basic block diagram of the smart antenna system, while Figure 6(a) shows a block diagram of the base station, and Figure 6(b) shows a block diagram of the mobile device with antenna direction is omni-directional. A PIC 16F877 microcontroller was used for the base station to control the beam selection of the antenna and a PIC 16F876 microcontroller was used for the mobile station to store some data and to control the transmitter station [21]. The AIS algorithm was implemented for processing the data in the controller system in order to choose the desired beam and monitor movement of the mobile device. A 2.4 GHz transceiver was used for the base station and the mobile device; in this case an X-Bee module was used as a prototype for transmitting and receiving to obtain sample data from the mobile device. The power supply used was a Ni-Cad battery for both the microcontroller and the transceiver module.

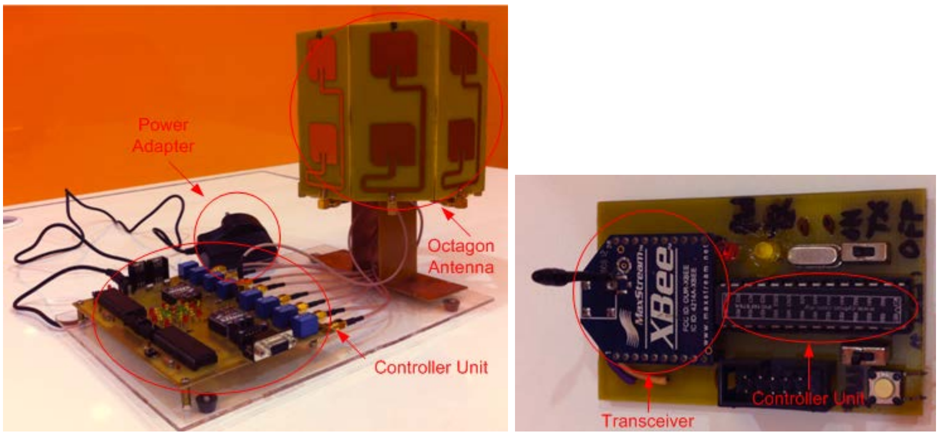


(a) (b)

Figure 6 Basic block diagram of switch beam smart antenna: (a) base station (b) mobile device.

A radio signal strength indicator (RSSI) is sent from the mobile device by the microcontroller to be used as reference for determining at which angle the strongest signal was received. In wireless communication systems path loss and multipath interference are common issues, as the base station receives many signals from different angles. To create an intelligent system, a few samples of the RSSI received by the base station are analyzed by the AIS algorithm in the process of determining the actual value of the signal strength and the selected signal strength value is then stored for use as reference for defining the beam switching. Once the system has detected the actual signal strength and the angle at which it arrives from the mobile device, the system will switch to the beam of a particular element of the array antenna to reach the desired user.

In the prototype also a LED was installed as an indicator of the desired beam switching by the system, meaning the actual desired beam direction of the antenna is shown by the LED indicator. While the user moves from one angle of direction to another, the system keeps comparing the previously received signal to the currently received signal and if any changes occur the system will define a new beam angle and switch to it. Figure 7 shows the fabricated prototype of the smart antenna system, while figure 7(a) shows the base station unit complete with microcontroller and between antenna units to controller feed by a 50 ohm coaxial cable and an SMAs connector. Figure 7(b) shows a prototype of the mobile device, for which an X-Bee module was used as transceiver at a frequency of 2.4 GHz (ISM band), as mentioned previously. A transceiver and a microcontroller were used for transmitting and receiving data. When the mobile device is set to active, the device keeps transmitting data packets, including the RSSI that will be received by the base station.



(a) (b)

Figure 7 Prototype of smart antenna system: (a) base station (b) mobile device.

Figure 8 shows details of the components in the controller unit, the X-Bee module used for transmitting and receiving data packets from the mobile device. A data packet received consists of a block of RSSI data that can be used as reference for the signal strength and to define the location or direction. A set of controllers was used to control all the processes and to decide to which antenna beam to switch. For the eight units a magnetic relay was used to switch the beam. Each relay represents one beam of the antenna and once the system has defined a beam to select, the LED indicator shows the direction of the mobile device.

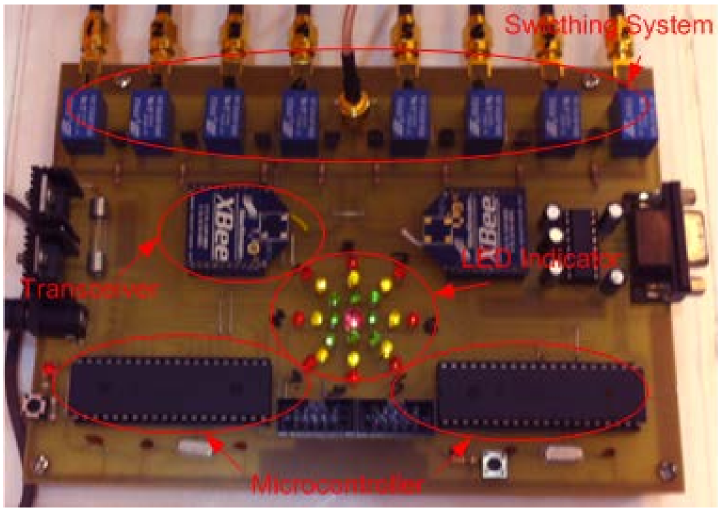


Figure 8 Controller unit of smart antenna.

4.1 Antenna Measurement Setup

The array antenna was assembled in an octagonal structure consisting of 8 elements that covers all angles in 360 degrees. To check the performance of the radiation pattern for every single antenna, angle measurements were needed. Figure 9 shows the measurement setup for the 8-element antenna in an anechoic chamber. In this setup all beams of the antenna were measured to confirm that every beam had a similar radiation pattern. A transmitter with a center frequency of 2.4 GHz was used in the anechoic chamber and a receiver with the same frequency was connected to a computer system to automatically plot the radiation pattern of the measured results. Measurement for all beams started from beam 1 going up to beam 8. The radiation pattern response results will be discussed in the next section.

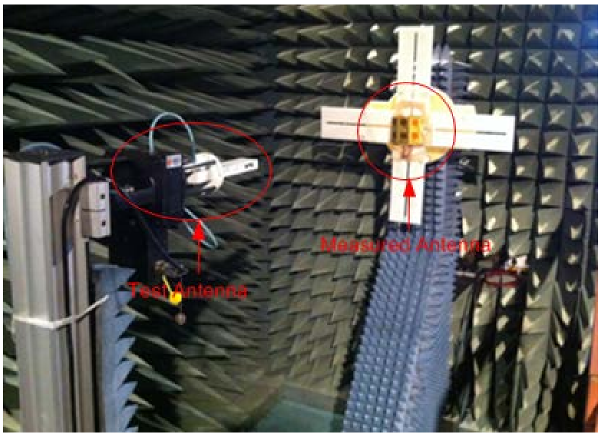


Figure 9 Measurement of radiation pattern of antenna in anechoic chamber.

Figure 10 shows a test that was done in a parking area, where a mobile device was placed and the smart antenna system had to select a beam. The first testing scenario was conducted by placing the mobile device in the direction of one of the beams. The distance between the base station and the mobile device was set to 5 meters, where all the received signal strength values were recorded by the base station. The same was done for the other beam directions, with the same distance and the same angle, recording all received signal strength values for comparison with each other.

The angle of each beam was indicated by the LED indicator on the module unit. The user made some movements to see if the system was able to scan the movements and switch to the correct beam angle. This test was carried out in an outdoor environment, where multiple signals are received by the system because the signal is reflected by surrounding objects. As mentioned before, for every beam the reference signal strength is 10 and the average signal strength is calculated as reference. According to the results, the system tested outdoors was able to switch the beam in the direction of the desired user but in the case of reflected signals, it sometimes missed reading the actual value. The complete results of received signal strength are shown below.

Figure 10 Field test of smart antenna system.

4.2 Implementation of Artificial Immune System Algorithm

Figure 11 shows a flowchart of the proposed algorithm while Figure 11(a) shows a flowchart of the negative selection algorithm and Figure 11(b) shows a flowchart of the algorithm processing the received signal and determining the actual received signal strength.

The use of an AIS algorithm in a smart antenna system is a method to determine the actual received signal strength from a mobile device, as the initial testing value of the RSSI received from each of antenna is not consistent. Specifically, a real value negative selection algorithm (RNSA) was used in this case. The real values of the received signal strength will be compared and analyzed by the processing unit without conversion to another unit, such as binary or octave numbers. Signal training is done in order to collect as many sample data as possible for various wireless communication scenarios. Figure 12 shows the complete process flow of digital signal processing (DSP), which starts with collecting the RSSI data and ends with the antenna beam being switched toward the user’s device.

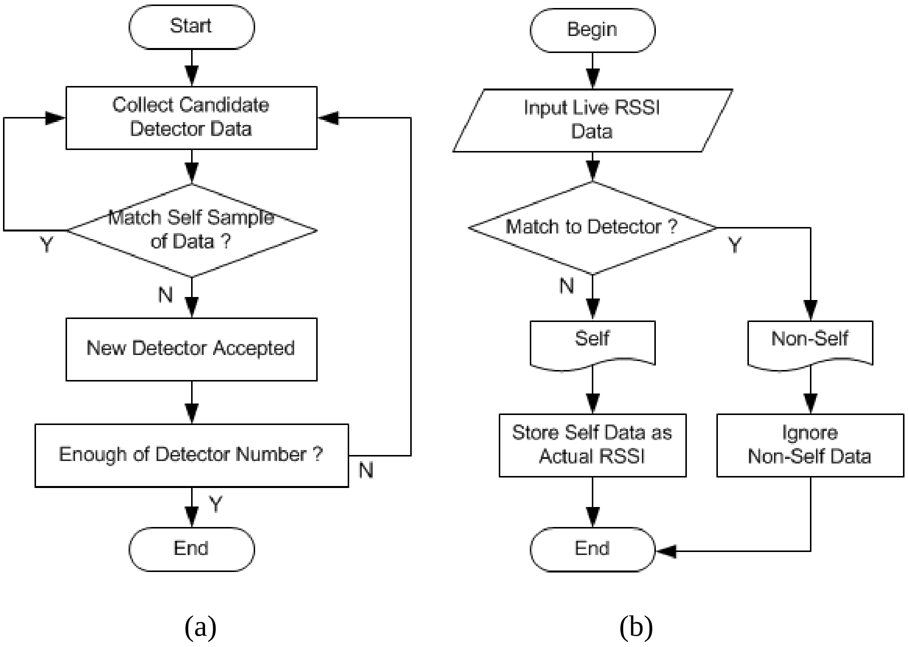


Figure 11 Flowchart of negative selection algorithm process flow: (a) detector set generation, (b) definition of actual RSSI value.

The basic concept of the AIS algorithm is to generate a detector by collecting as many sample data as possible for the training process, after which the detector set will check and define the signal or value to be processed, based on the requirements. Once the actual value of the received signal strength is determined, the next process step is to analyze which value is the highest. The antenna directed toward the mobile device should have the highest value because of the direct beam. A mobile device was used as the transmitter and was programmed to continuously transmit data to the X-Bee module with RSSI data included in the packet. The values were determined by signal processing to be analyzed as live data and candidate of the detector set generated. The AIS algorithm determines the values of the live data based on the detector set, where the number of detectors is normally higher than the number of data to be processed. In this case the number of data samples to be analyzed was 10 samples and 100 samples. For the number of live data (10), the number of detector sets generated was 50 and for the number of live data to be analyzed (100) the number of detector sets was 500, which is five times more compared to the live data. After the real RSSI values have been determined for each antenna beam, the controller will select the beam with the highest RSSI value, representing the angle of arrival (direction of arrival) of the signal from the user device.

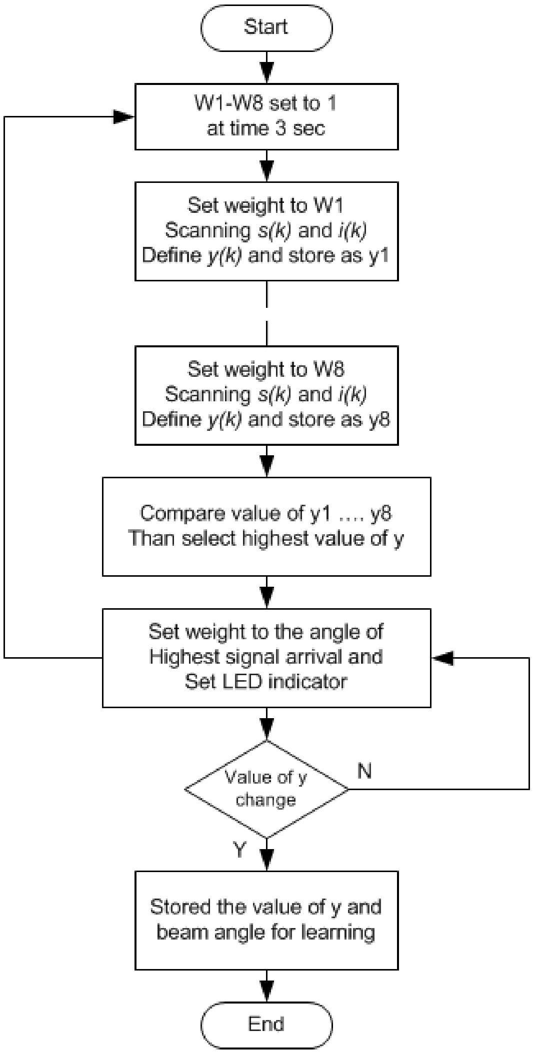


Figure 12 Flowchart of algorithm executing smart antenna system process.

5 Results and Discussion

In this section we discuss the reflection coefficient results of a single array antenna obtained during simulation and measurement. Figure 13 shows a graph of the reflection coefficient of the antenna with parametric studies.

The simulation result of the single array antenna as shown in graph was -16.8 dB at an operating frequency of 2.4 GHz, while the measured value, shown as a dotted line, shows good agreement with the simulation result, being -19.1 dB. The bandwidth covered by the single array antenna for the 2.4 GHz ISM band was 2.40-2.483 GHz. The parametric study results were achieved by adjusting the width of the antenna patch (w). The value "a" represents the best reflection coefficient in performance. Although the main response was at 2.535 GHz, the overall bandwidth coverage started from 2.278 GHz going up to 2.615 GHz. The other results of the parametric studies were within the range of the wireless LAN band 2.4 GHz (ISM) with a wide bandwidth achieved. The final value chosen for the width of the antenna patch was a = 17, because in performance this was the best reflection coefficient.

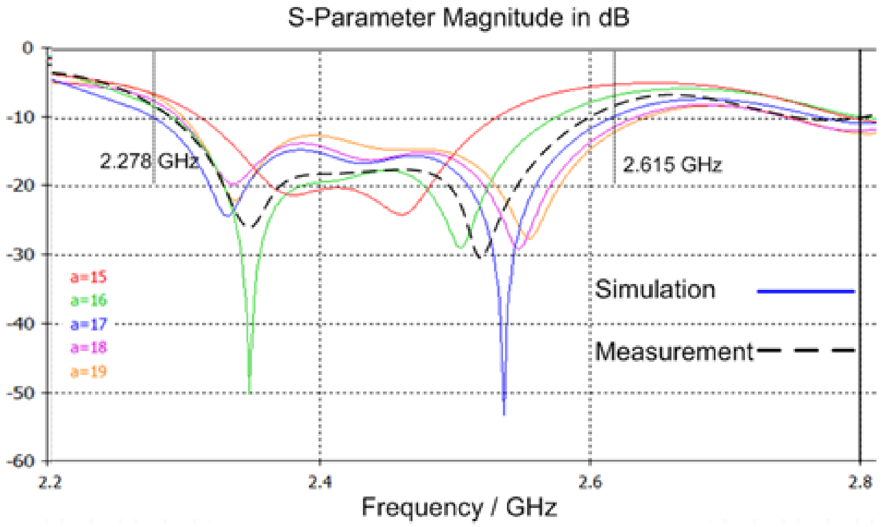
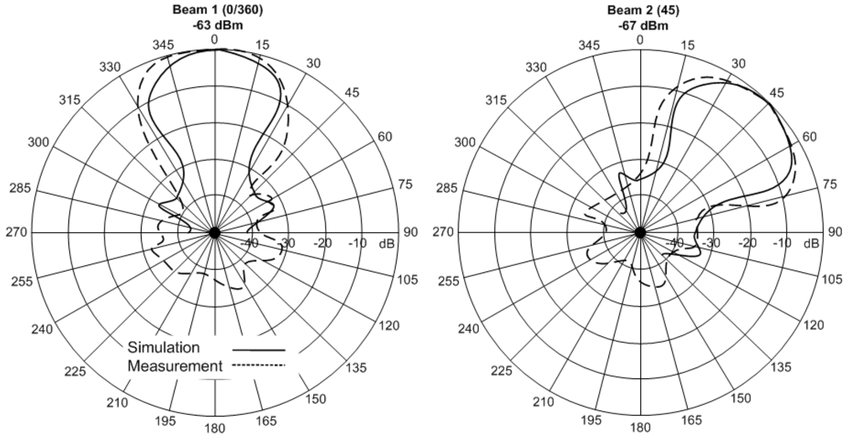


Figure 13 Reflection coefficient of single array antenna.

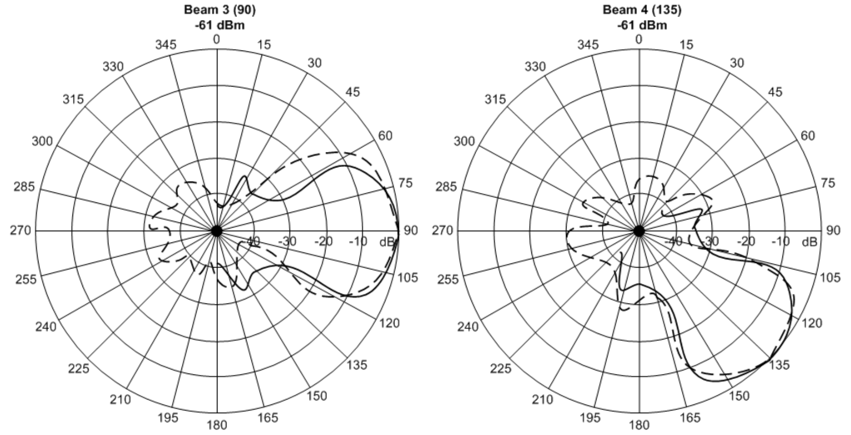
Table 1 shows the results of the signal strength values that were collected while the mobile device was placed in the direction of each beam respectively. The signal strength received by all beams was recorded. Starting with the first beam, directed at 0 degrees, all the signal values received by the base station were recorded, until the last beam at 315 degrees. In this test, as mentioned above, the distance of the mobile device to the base station was set to 5 meters, with the purpose to check the values and compare all beams with each other. The highest value was supposed to belong to the beam with the shortest distance to where the mobile device was placed and the lowest to the back lobe of the antenna. The highest received signal strength value was -61 dBm, as shown in Table 1, while the lowest was -101 dBm, where the beam was the furthest from the mobile device. The highest value represents the actual angle where the signal comes from; the microcontroller system uses this value to switch the beam of the antenna to the angle of the user beam.

Table 1 Received RSSI Values of from Beam 1 to Beam 8.

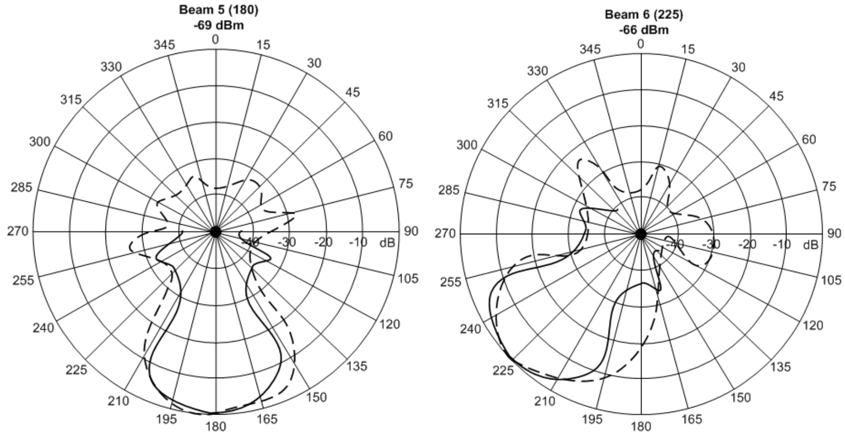
Mobile Device Location (degrees)	RSSI Value (dBm)							
	Beam 1	**Beam 2**	**Beam 3**	**Beam 4**	**Beam 5**	**Beam 6**	**Beam 7**	**Beam 8**
0	**-63**	-73	-85	-94	-101	-92	-80	-75
45	-71	**-67**	-73	-82	-95	-98	-95	-82
90	-83	-75	**-61**	-70	-80	-91	-100	-93
135	-95	-80	-75	**-61**	-73	-83	-92	-99
180	-98	-93	-84	-71	**-69**	-71	-83	-90
225	-92	-100	-93	-83	-72	**-66**	-72	-85
270	-85	-91	-100	-90	-84	-75	**-63**	-73
315	-73	-83	-95	-98	-95	-85	-70	**-63**



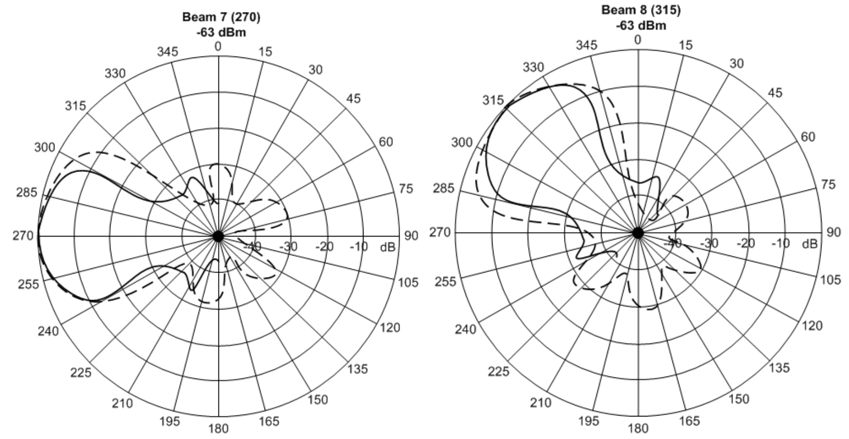
(a) 0/360 degrees (b) 45 degrees



(c) 90 degrees (d) 135 degree



(e) 180 degrees (f) 225 degrees



(g) 270 degrees (h) 315 degrees

Figure 14 Measurement of radiation pattern of 8-element antenna: (a) 0/360 degrees, (b) 45 degrees, (c) 90 degrees, (d) 135 degrees, (e) 180 degrees, (f) 225 degrees, (g) 270 degrees, (h) 315 degrees.

The signal strength values collected for each beam direction were analyzed by the AIS algorithm while the mobile device was placed in one of the beam directions, in this case at the 0 degrees position. For every beam direction, 10 data samples of signal strength were collected and the average value of the signal was calculated as a reference to determine the actual signal of the represented beam. These signal values were compared to the other beam directions to select the one with the highest value as the angle of arrival.

For the simulation and measurement results of the radiation pattern of the smart antenna system for each obtained beam angle, the simulation results are indicated by a line, while the measurement results are indicated by a dotted line. Both simulation and measurement results gave good agreement with the radiation pattern response. Figure 14 shows a graph of the radiation pattern for both simulation and measurement, where Figure 14(a)-(h) show a radiation angle of 0/360 degrees, 45 degrees, 90 degrees, 135 degrees, 180 degrees, 225 degrees, 270 degrees and 315 degrees, respectively. The results show the average of every angle with a beamwidth of 45-55 degrees. The results of the radiation pattern measurements fulfill the requirements of the proposed coverage area of the antenna as mentioned before.

6 Conclusion

A switch beam smart antenna system for WLAN application has been simulated, measured and tested. An AIS algorithm was implemented for data processing and determining the angle of arrival (beam direction) of the mobile device. The antenna system uses radio signal strength as reference in the data processing. The method used collects a number of signal strengths as reference and analyzes them by implementing the AIS algorithm and also using a learning concept based on past behavior of data. The proposed antenna was fabricated using FR4 material. The prototype system used a PIC 16F877 microcontroller for the base station and a 16F876 microcontroller for the mobile device. The smart antenna system design used 2.4 GHz (ISM band) as the frequency for transmitting and receiving. An X-Bee module was used that operated in the 2.4 GHz frequency band. The octagonal structure of the array antenna consisted of 8 elements, where each element covered 45 degrees. The radiation pattern of the array antenna has been measured. The results show that the simulation and measurement data of the radiation pattern were in good agreement and gave a good response. Testing of the antenna as WLAN base station showed that the system was able to direct the antenna beam to the user’s device also while the user was moving.

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