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A Cognitive Radio based for Smart Grid AMI Network using Adaptive Algorithm

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Abstract

Maximum utilization of unused license spectrum is one of key factor in cognitive radio network which can handle the large number of systems and devices connected on smart grid AMI network. The central intelligence control system has responsibility to accept new technologies and users for automation. To ensure a reliable communication in smart grid system through cognitive network, a minimum mean square error (MSE) signal using unused licensed spectrum (or frequency) is necessary to be detected with small decision error. In this paper, we introduce a user control wireless smart grid system with minimum MSE using LMS algorithm.

Keywords: *spectrum, cognitive radio, smart gird, AMI, LMS.*

1. Introduction

Today's challenge is the control of an enormous number of systems and devices which are distributed over a large geographic area easily in a smart grid network. The electrical power grid which starting from power generation, managed in transmission for safely delivering to the customer is centrally controlled by an intelligence computerized network capabilities. Due to rising in demand, aging infrastructure, less opportunities for remote management are major issue of old smart grid systems. Moreover, due to economic and environment concerns an attention on renewable energy resources and existing fuel-based power generation is rapidly increasing. Day by day development of technologies on automation and communications has broadened the concept of control management in smart grid so that it can cover diverse areas of application in different sectors.

Smart grid used different communication technology known as wireless and wired communication over

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both licensed and unlicensed spectrum bands. Today's smart grid incorporate alternatives of sources of energy as well as integrated power generation with emerging technologies such as wireless communication, adaptive control system and pervasive computing which improves reliability, efficiency and sustainability. NIST [1] conceptual model paradigm provides a real-time information by connecting intelligence appliances, sensor, smart meters and electric machines which is depicted in Figure 1.

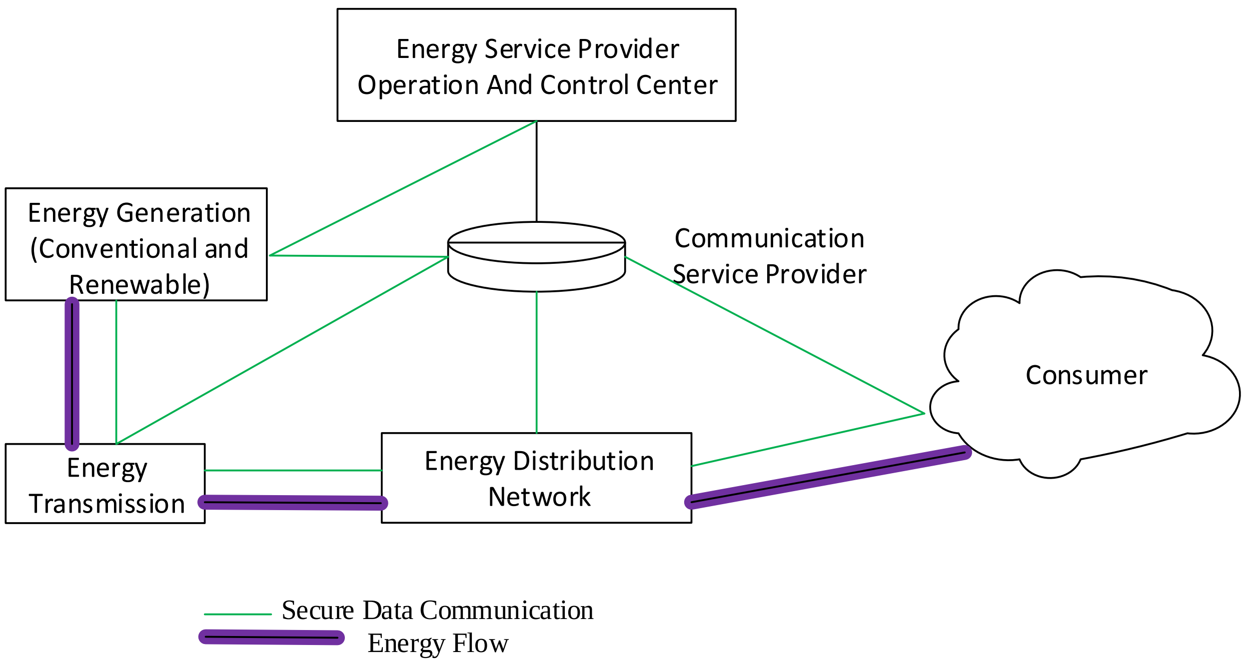

Figure 1. Sample Smart Grid Conceptual Model

Nowadays, a reliable communication infrastructure is require which can accommodate existing and upcoming application and provide real–time information, critical monitoring, and data exchange with minimum delay and signaling with high probability [2]. A scalable communication infrastructure satisfying its requirements while providing reliable services increases the demand of radio frequency (RF) (or spectrum). However, spectrum of radio frequency is limited so that spectrum bands are assigned to licensed networks and users within certain geographical area. Measurements of unused spectrum by the licensed user for significant periods of time, spectrum can be utilized [3], [4]. The amount of data acquired bandwidth of smart meters and sensor in a smart grid AMI (automatic metering infrastructure) network has grown dramatically from 10,780 Tbytes to 75,200 Tbytes in 2015 [5]. With such rapid increase of applications, suddenly a severe shortage of spectrum happens but it is found that actually utilized spectrum is very limited and little. To solve this problem, utilization of unused spectrum at a time by other user who does not hold the license is proposed.

In this paper, we used adaptive least mean square (LMS) beam forming algorithm in cognitive radio environment which utilizes maximum frequency spectrum through high probability of accessing. LMS algorithm has capability to minimize the error of detected signals in adaptive way, which becomes crucial development in smart grid network on high probability cognitive radio network.

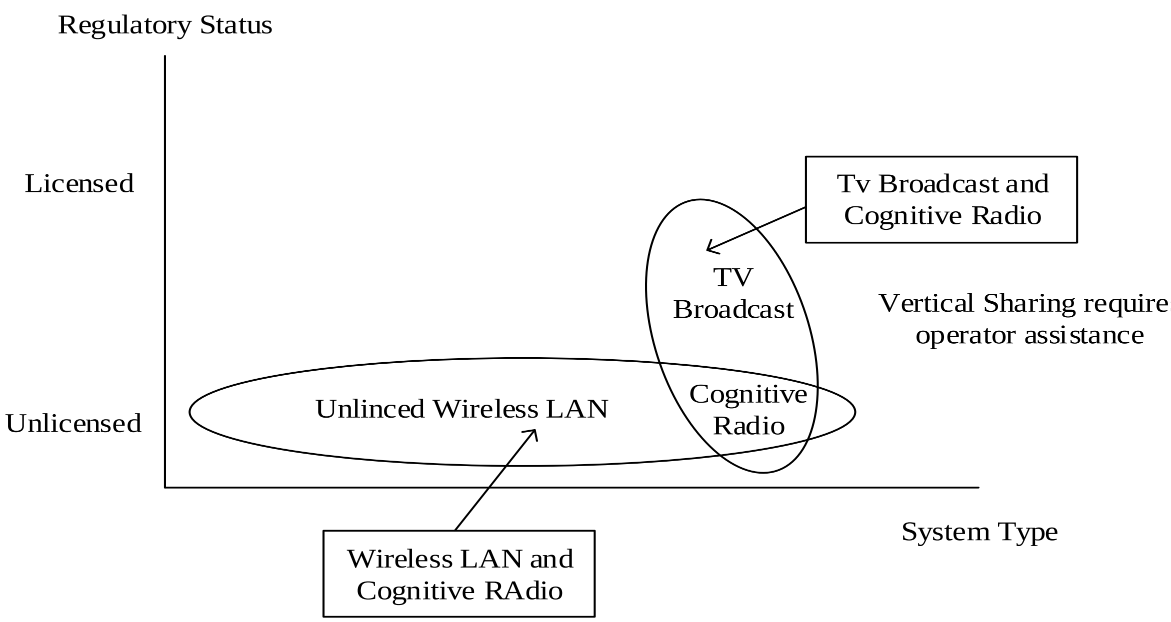

Figure 2. Spectrum Sharing Technique

In this paper, in order to detect RF signal spectrum with high unused probability by primary licensed users, smart antenna system using LMS algorithm are taken into account. In smart antenna system, LMS algorithm adopts weight vector which receives two–way wireless communication channel signal, a unlicensed RF spectrum turns in high probability. It is assumed that the cognitive-AMI system uses multiple antennas with LMS algorithm to find high probability of unused RF signal.

Users who want to control their electric systems by using AMI network refer to primary users. Each load appliance of each load system is uniquely defined by the AMI system to the primary user who wants automatic computation through cognitive radio networks. Taking advantage of unused license spectrum, LMS algorithm provides the training or reference signal with least mean square error (MSE) becomes more beneficial at unused license spectrum in wireless system such as Wi-Fi, ZigBee, sensor network. Due to random behavior of signal transmission and different threshold levels in reception side we used Maximum probability in detecting respective user's appliance.

2. Cognitive Radio

Cognitive Radio is an adaptive, intelligent radio and network technology that can automatically detect available channels in a wireless spectrum and change transmission parameters enabling more communications to run concurrently and also improve radio operating behavior. The unutilized part of the RF spectrum has spectrum holes or white spaces (WS) which can be seen Figure 3. Those white spaces are allowing for no hold licenses user at a real time in a certain geographic area. Cognitive radio communication systems are aware of their environment and internal state and can make decisions about their radio operating behavior based on that information and predefined objectives. There are two types of cognitive radio system considered: one is co-operative and other is non-cooperative. The cooperative centralized cognitive radio network architecture which has a centralized server maintains a database for spectrum availability. The information is received form the group of primary users.

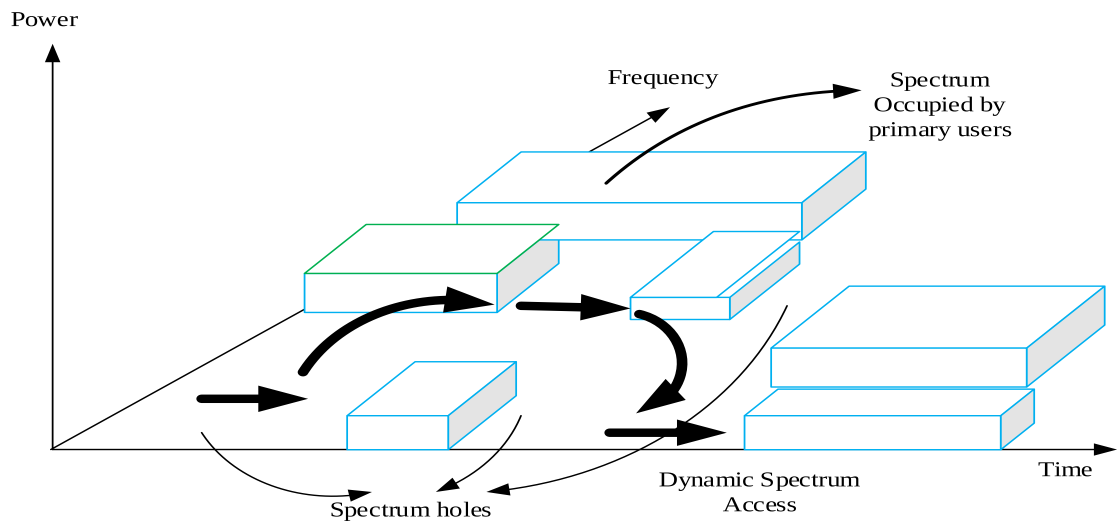

Figure 3. Frequency Allocation in Cognitive Radio

3. Least Mean Square (LMS) Algorithm in AMI with Cognitive Radio Concept

The smart antennas are widely used for wireless communication because it has an ability to increase the coverage capacity of a communication system. The main purpose of the smart antenna system is the selection of smart algorithms like LMS, NLMS and RLS for adaptive array. By using LMS adaptive beam forming algorithms the weight of the antenna array can be adjusted to form certain amount of adaptive beam to track corresponding users automatically and to minimize interference arising from others by introducing nulls in their direction. The interference can be suppressed and the desire signal can be extracted [6]. There are mainly normalized array factor and mean square error is used to measure the efficiency of LMS algorithm for the wireless communication systems.

3.1 LMS Algorithm in Smart Antenna

LMS algorithm is adaptive and Non-blind algorithm because it uses the training or reference signal. It uses the gradient based steepest decent method. It follows an iterative procedure that makes successive corrections to the weight vector in the direction of the negative of the gradient vector which eventually leads to the minimum mean square error [7]. LMS algorithm is relatively simple and it does not require correlation function calculation and matrix inversions [8]. Figure 4 shows an algorithm block diagram.

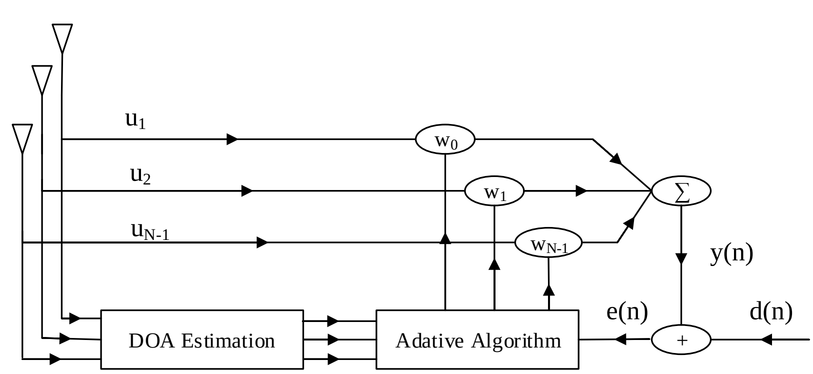

Figure 4. LMS algorithm block diagram

The linear combination of input vector u(n) and weight vector **w**(n) is the output of uniform linear antenna y(n) at any time n is given by

$$y(n) = w^H(n)u(n) \tag{1}$$

where $w^H = [w_1, w_2, \dots \dots \dots \dots \dots . . w_N]^T$ is weight matrix and $u(t) = [u_1(n), u_2(n) \dots \dots \dots \dots \dots \dots . [u_N(n)]^T$ is the matrix of Signal Vector .The error signal among sensor outputs can be calculated as

$$e(n) = d(n) - y(n) \;,$$
$$y(n) = d(n) - e(n) \tag{2}$$

From the method of steepest descent, the weight vector w(n+1) can be written as

$$w(n+1) = w(n) + \frac{1}{2}\mu[-\nabla \mathrm{E}\{e^2(\mathrm{n})\}] \tag{3}$$

where μ is the step size parameter, which controls the convergence characteristics of the LMS algorithm. Its value lies between 0 and 1. And $e^2(\mathrm{n})$ is the mean square error (MSE) between the beam former output $y(n)$ and the reference which is given by

$$e^2(\mathrm{n}) = [d^*(n) - w^h u(n)]^2 \tag{4}$$

The gradient vector in the above updated weight equation can be computed as

$$\nabla(E\{e^2(n)\}) = -2r + 2Rw(n) \tag{5}$$

In the steepest descent, the biggest problem is the computation involved in finding the values cross-correlation vector r and auto correlation matrix R in real time.

The LMS algorithm on the other hand simplifies this by using the instantaneous values of covariance matrices r and R instead of their actual values i.e.

$$R(n) = u(n)u^h(n)$$
$$r(n) = d^*(n)u(n)$$

Therefore the updated weight can be calculated by the following equation,

$$w(n+1) = \mathrm{w}(n) + \mu u(n)[d^*(n) - u^h(n)w(n)] \tag{6}$$

$$\mu = \frac{w(n+1) - \mathrm{w}(n)}{\mathrm{u}(n)e^*(n)} \tag{7}$$

where, $e^*(\mathrm{n}) = \mu[d^*(n)u(n) - u(n)u^H(n)]$. The response of LMS algorithm is determined by three principal factors step size parameter, number of weights and eigenvalue of the correlation matrix of input data vector.

3.2 Implementation of LMS Algorithm on Cognitive Network.

Advanced Metering Infrastructure (AMI) system takes advantage of LMS algorithm for increasing number of load connection by automatic balancing system. It can take large amount of load by increasing its sensing area in LAN, MAN, WAN. AMI system is an intelligence computing network which has server and database. It can access user command as input and control the user's appliances as per need.

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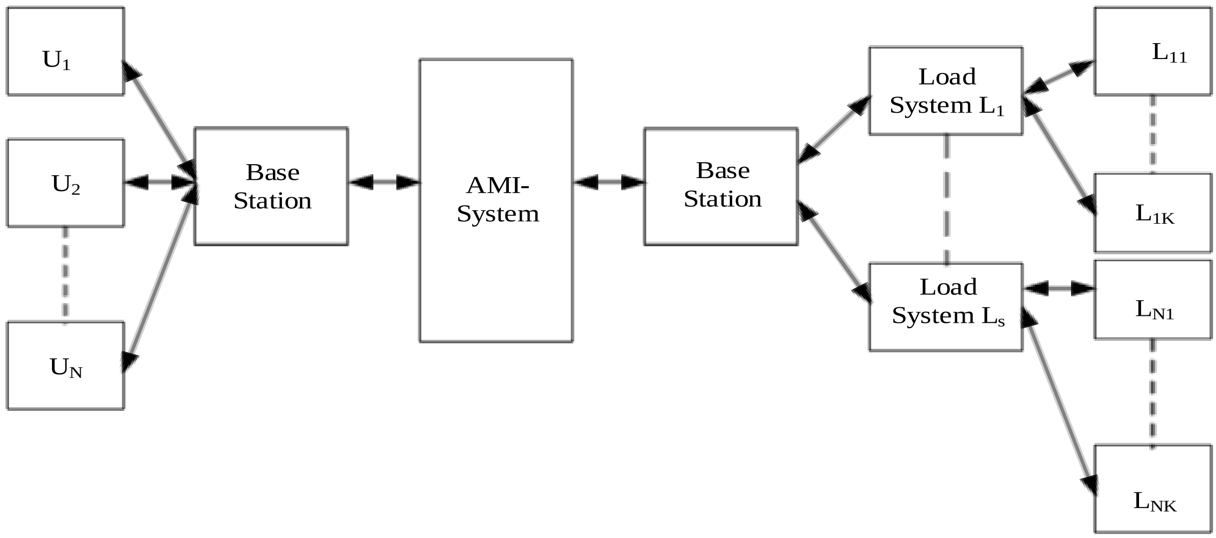

Figure 5. AMI block diagram

Let we have $L_1, L_2 \ldots\ldots L_S$ be the number of load system which connected from wireless system to AMI. Each load system has different number load appliances such as $L_{11}, L_{12} \ldots\ldots L_{1k}$. Let us consider we have equal number of load appliances in each system. A load matrix which has $L \times S$ in dimension. A primary user U_N is want to control one of his appliances L_{11}. User send a command which is decoded by the AMI-system. AMI system already getting information about that load system which is storage in memory. Using user control system it command to see that appliance working condition and reply to the user.

$$U = S^H \times L \tag{8}$$

The performance of measuring energy detector based on sensing probabilities. P_D is the probability of considering frequency signal which is truly present. The desiring RF spectrum is large so that we can formulated probability of spectrum as high as possible.

$$P_D = P_r(M > \lambda_E | H_1), \\ P_D = P_r(M = \mu | H_1) \tag{9}$$

where (H_1) are hypothesis [8] such that

$$H_1 \colon y(n) = s(n) + Z(n) \tag{10}$$

where $s(n)$ & $Z(n)$ refers to the detected and white Gaussian noise. At the time of receiving information in AMI, the error signal is considered as white noise. From Eq. (2) and (10) we can say

$$y(n) = s(n) - e(n) \ . \tag{11}$$

Finally energy detection methods converges to

$$P_D = 1 - \Gamma\left(L_f L_t, \frac{\lambda_E}{\sigma^2{}_s - \sigma^2{}_e}\right) \tag{12}$$

where λ_E is decision threshold and $\Gamma(a, x)$ is the incomplete Gamma function. A signal-to-noise-ratio (SNR) is defined as the ratio of the primary user's signal to noise power.

$$SNR = {\sigma^2}_s / {\sigma^2}_e$$

The waveform based sensing metric can be obtained as

$$M = Re[\sum_{n=1}^{N} y(n)s^*(n)] \quad (13)$$

where * represents the conjugate operation. Let LMS system works in unlicensed frequency with maximum probability. The final Eq. (14) is for primary user which can detect his appliances through LMS algorithm like as follow:

$$U = S^H \times L \times \left(1 - \Gamma\left(L_f L_t, \frac{w(n+1) - w(n)}{u(n)e^*(n)({\sigma^2}_s - {\sigma^2}_e)}\right)\right). \quad (14)$$

4. Simulation Result

For the MATLAB simulation we take different values of μ in Eq. (7) as it also use for calculating threshold of unlicensed frequency spectrum in Eq. (14). μ is the step size parameter which controls the convergence characteristics of the LMS algorithm between 0 and 1.When a primary user want to control, his appliances utilize LMS algorithm in AMI system provides a minimum MSE signal with higher probability. Thus, the primary user can find the strong signal among many interference signals. That is, while the primary user can utilize his high reliable signal, the secondary users who want to use unused spectrum of the primary user can also fins the other strong signal with smart antenna system with LMS algorithm.

In Figure 6, the array factor (AF) of LMS algorithm of the primary user in Eq. (14) is plotted. It is noted that AF depends on number of elements, elements spacing, amplitude and phase of the applied signal to each elements. The number of elements and elements spacing determine the surface area of the overall radiating structure. This surface area is also called aperture. Larger the aperture results in higher gain.

In the simulation in Figure 6, it is assumed that three numbers (N) of antenna array elements such as 5, 9 and 12 are taken into account and the space between them is 0.5 and desired signal is arriving at 0 degree and other interference angle of -30 degree. The simulation result shows that when number of antenna array element increasing from small number to large number then the beam width become narrow and the number of side lobes goes on increasing. That is, when the number of antenna array element is increased, the size of beam is narrowed, this result in the number of user can be increased. It is noted that when the primary user with licensed spectrum with smart antenna increases the number of antenna array element, the more secondary users with smart antenna can also utilize the (unused) licensed spectrum.

Figure 7 shows the performance of LMS algorithm when the distance between the antenna array elements is 0.125λ, 0.25 λ and 0.5 λ and the desired signal is arriving angle at 0 degree, interference is at an angle of -30^0 and number of elements are assumed as 14. The simulation result shows that array element produces narrow beam when inter element spacing is increased. When the separation distance between antenna array elements is equal to the length of granting lobs are created. It is noted that when the distance between antenna array element is increased, the size of beam is narrowed. Thus, as in Figure 6, when the primary user with licensed spectrum with smart antenna increases the distance between antenna array element, the more secondary users with smart antenna can also utilize the spectrum.

The simulation results shows that when simultaneously increase in number of array elements and distance between them of the primary licensed user, the decision threshold width in Eq. (12) and (14) of cognitive-AMI system with smart antenna using LMS algorithm becomes sharper. With such sharping RF spectrum lobe of antenna, the probability of unused spectrum utilization becomes higher. As a result more number of unlicensed user can be increased in smart grid connection system.

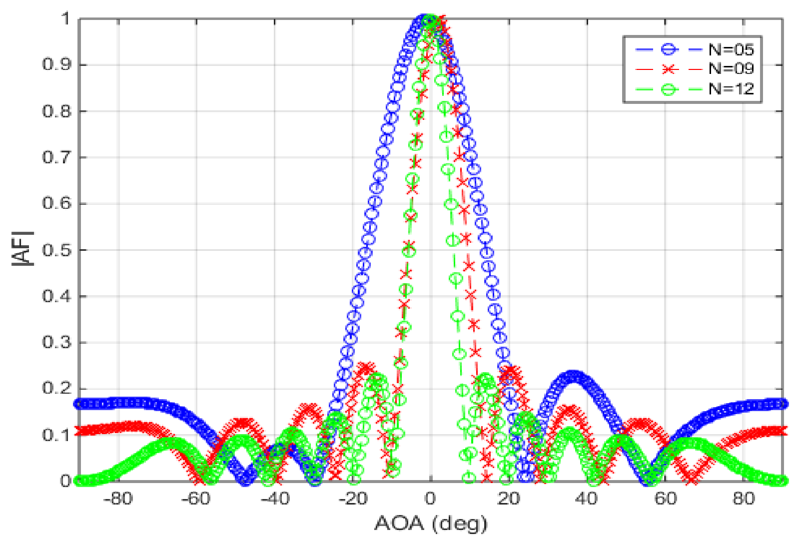

Figure 6. Array factor plot for LMS algorithm with AOA for different array element

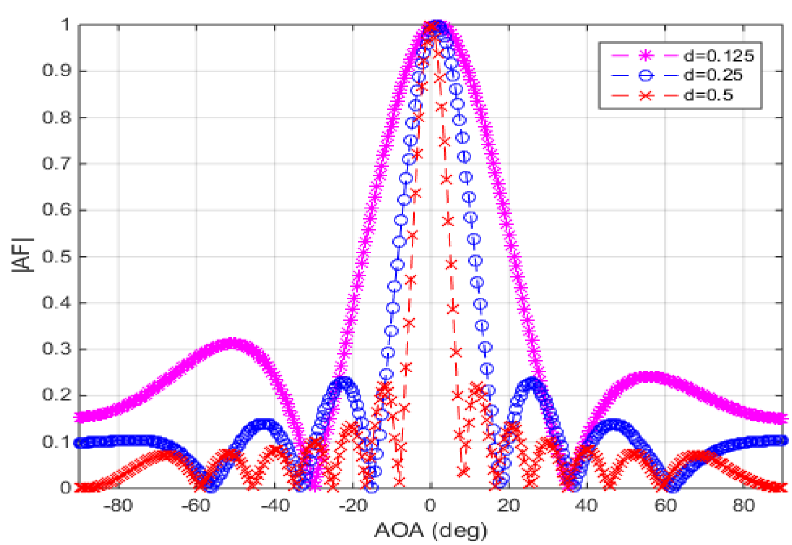

Figure 7. Array factor plot for LMS Algorithm with AOA for different distance

5. Conclusion

A smart grid AMI system becomes more practicable by using smart antenna with LMS algorithm in cognitive radio network which increases the higher probability function. The simulation results showed that when simultaneously increase in number of array elements and distance between them of the primary licensed user, the decision threshold width of cognitive-AMI system with smart antenna using LMS algorithm becomes sharper. Thus, cognitive-AMI system can take maximum number of user in automatic environments. With such sharping RF spectrum lobe of antenna, the probability of unused spectrum utilization becomes higher. As a result more number of unlicensed user can be increased in smart grid connection system.

Acknowledgement

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