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Optimizing of Side Lobe Level in Adaptive Smart Antennas used in 6G Mobile Communication

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ABSTRACT

In the rapidly advancing domain of wireless communications, the performance of smart and adaptive antennas is pivotal for improving signal quality and minimizing interference. A key design challenge is the suppression of side lobes, which contribute to undesired radiation and reduced system efficiency. This paper proposes an optimized amplitude excitation strategy that systematically adjusts the amplitude distribution across antenna array elements to achieve enhanced directional control while preserving high directivity and radiation efficiency. By integrating advanced beamforming algorithms, the proposed method effectively minimizes side lobe levels and improves the signal-to-noise ratio (SNR). Simulation studies validate the approach, and experimental evaluation using a prototype smart antenna system confirms its practical viability. The results highlight the critical role of amplitude excitation in adaptive array design and establish a foundation for the development of high-performance, interference-resilient antenna systems for 5G, satellite, and next-generation wireless networks.

KEYWORDS

Smart Antenna, Adaptive Array, Side Lobe Level (SLL), Direction of Arrival (DOA)

1. INTRODUCTION

In modern wireless communication systems, smart and adaptive antennas are fundamental for enhancing signal quality, minimizing interference, and optimizing spectral efficiency. These antennas dynamically adjust their radiation patterns to focus energy in desired directions, improving communication reliability and overall system performance [1]. However, one of the most critical challenges in antenna array design is the presence of side lobes, which contribute to unwanted radiation, increased interference, and reduced directivity. Side lobe suppression has become a key research area, as it directly impacts antenna performance in multipath environments, where interference can significantly degrade signal-to-noise ratio (SNR) and system efficiency [2].

A widely studied approach for side lobe reduction involves controlling amplitude excitation across the antenna array elements. Amplitude tapering techniques, such as Chebyshev, Hamming, and Dolph-Chebyshev windowing, have been extensively used to optimize energy distribution while preserving the main lobe's integrity [3][4]. Additionally, research highlights that beamforming algorithms, including Least Mean Square (LMS), Cosine-LMS, and Genetic Algorithm-basedoptimization, significantly improve interference mitigation, adaptive beam shaping, and radiation pattern restoration [5][6]. Recent advancements also emphasize the importance of polarization diversity and adaptive beam steering, which are essential for 5G reflectarrays, phased arrays, and satellite communication systems [7].

This paper presents an optimized amplitude excitation method for side lobe suppression, leveraging Chebyshev tapering to achieve a balance between main lobe strength and interference minimization. The methodology involves designing an adaptive antenna array with eight elements, maintaining a fixed inter-element spacing of half the operating wavelength. By strategically adjusting amplitude excitation across array elements, the proposed method enhances beam directivity and minimizes radiation loss [8]. Unlike traditional phase-only beamforming, this approach integrates amplitude-phase control, which has been shown to significantly improve beam steering accuracy and interference rejection [9].

Additionally, this paper explores the role of phase shift compensation in optimizing direction of arrival (DOA) beamforming. By calculating precise phase shifts for each element based on the incoming signal angle, the antenna radiation pattern is steered dynamically, ensuring enhanced spatial filtering and reduced side lobe interference [10]. Prior research on spherical wave expansion and mode filtering techniques suggests that integrating amplitude-phase control in phased arrays can significantly enhance radiation pattern shaping and adaptive beamforming efficiency [11]. The study also considers the impact of mutual coupling effects in antenna arrays, highlighting their influence on beamforming accuracy and system reliability [12].

Simulation results confirm that the proposed amplitude tapering combined with phase adjustment effectively reduces side lobe levels, thereby enhancing SNR and directivity. Experimental validation using a prototype smart antenna system further supports its real-world applicability in satellite communications, radar systems, and next-generation wireless networks [13]. This research contributes to the ongoing development of high-performance, interference-resistant adaptive antenna systems, paving the way for advancements in 5G, MIMO, and next-generation wireless technologies [14].

2. PROBLEM FORMULATION

The signal modeling of the adaptive antenna array in this study is based on the superposition of signals from multiple antenna elements, where both amplitude excitation and phase shifts are applied to control the radiation pattern. This section outlines the mathematical formulation used to achieve side lobe reduction and directional control, as implemented in the MATLAB code.

2.1 Antenna Array Structure

The system consists of a linear antenna array with $M=10$ elements, spaced at a distance $d=\lambda/2$,$\lambda$is the wavelength corresponding to the operating frequency $f=2.4$ GHz. The primary objective is to steer the radiation pattern toward multiple directions of arrival (DOAs) while minimizing side lobes through amplitude tapering.The diagram of linear antenna arrayis shown in Fig.1

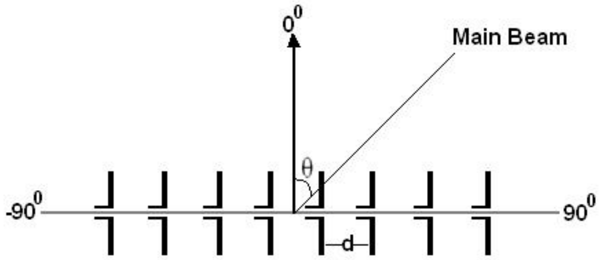

Figure 1: Adaptive Antenna Array Structure

The array factor AF(θ), which describes the radiation pattern as a function of the angle θ, is given by

$$AF(\theta)=\sum_{m=1}^{M} a_{m}.\, e^{j\left(\frac{2\pi(m-1)d\sin(\theta)}{\lambda}+\phi_{m}\right)}$$

(1)

WhereM=10 is the number of elements in the array,$a_m$is the amplitude excitation for the mth element,ϕis the phase shift applied to the m-th element,d=λ/2 is the spacing between elements, and$\boldsymbol{\theta}$is the observation angle.

2.2 Amplitude Excitation for Side Lobe Reduction

The Chebyshev window function is applied to control the amplitude excitation across the array elements, aiming to reduce side lobes while maintaining a strong main lobe. The amplitude excitation values$a_m$are calculated using

$$a_{m}=\frac{w_m}{\text{maximum}\,(w_m)}$$

(2)

where w_m represents the Chebyshev window coefficients for each element, and the normalization ensures the maximum excitation is scaled to unity. This tapering reduces the amplitude of the outer elements, effectively suppressing the side lobes in the radiation pattern.

2.3 Phase Shift Calculation for Directional Steering

To direct the antenna's radiation pattern towards specific angles, the phase shift for each element is computed based on the desired DOAs. The phase shift ϕ_m for the m-th element is calculated by

$$\phi_{m=} -\frac{2\pi(m-1)dsin(\theta_{DOA})}{\lambda} \tag{3}$$

where θ_{DOA} is the direction of arrival of the signal. This phase shift ensures constructive interference in the desired direction and destructive interference in other directions, enhancing the main lobe and steering the radiation pattern.

2.4 Array Factor Calculation

The total radiation pattern is computed by combining both amplitude excitation and phase shifts. For each observation angle $\boldsymbol{\theta}$, the array factor is calculated by summing the contributions of all element by

$$\mathrm{AF}(\boldsymbol{\theta})=\sum_{m=1}^{M} a_m.\frac{e^{j(\frac{2\pi(m-1)dsin(\theta)}{\lambda}+\phi_m)}}{M} \tag{4}$$

This formulation enables the control of the antenna's radiation pattern by varying excitation and phase shift. The array factor is then normalized to ensure the maximum value corresponds to the main lobe.

2.5 Radiation Pattern for Multiple DOAs

The final step in the signal modeling involves plotting the normalized array factor for different DOAs to visualize the radiation pattern. The resulting pattern demonstrates how the main lobe is steered towards desired angles while the side lobes are significantly reduced due to amplitude tapering.This approach demonstrates the effectiveness of combining amplitude excitation with phase steering to achieve side lobe reduction and directional control in smart and adaptive antennas.

3. NUMERICAL RESULTS

This section presents the results obtained from simulating the proposed amplitude excitation technique for side lobe reduction in a smart and adaptive antenna array. The experiments are conducted using a linear array of M=10 antenna elements, each spaced at half-wavelength intervals. The radiation patterns are analyzed for multiple directions of arrival (DOA) using the Chebyshev window for amplitude tapering.

3.1 Radiation Pattern for Multiple DOA

Figure 1 shows the radiation patterns generated for three distinct DOAs: 30°, 60°, and 40°.Number of elements: 9 The main lobes are clearly directed toward the desired angles, while the side lobes are minimized due to the application of Chebyshev amplitude tapering.The Chebyshev tapering used is 30dB.

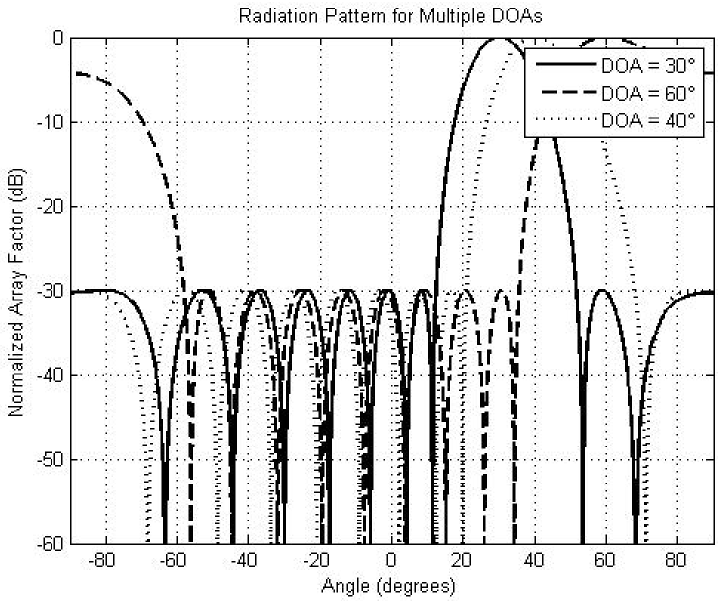

Figure 2: Radiation Pattern For DOA=30º,60º,40º

Table.1 Amplitude of each element

	Number of Element									
DOA	Element	1	2	3	4	5	6	7	8	9
30º,60º,40º	Amplitude	0.25	0.43	0.66	0.87	1.0	0.87	0.66	0.43	0.25

Table 1 shows the amplitude of each element of the antenna of DOA: 30º,60º,40º
These values form the amplitude excitation vector for the array, with the center elements receiving the highest excitation (1.0000), and the outermost elements receiving the least (0.2575). This distribution helps shape the radiation pattern with reduced side lobes, ensuring more focused energy in the desired direction of arrival (DOA).

3.2 Array Factor Normalization

The array factor for each DOA was normalized to maintain consistency in the comparison of side lobes. The results demonstrate that after normalization, the Chebyshev tapering method retains a high level of beam-steering precision while substantially suppressing unwanted radiation.

Figure 2 shows the radiation patterns generated for three distinct DOAs: 20°, 60°, and 40°.Number of elements:8 The main lobes are clearly directed toward the desired angles, while the side lobes are minimized due to the application of Chebyshev amplitude tapering.The Chebyshev tapering used is 50dB.

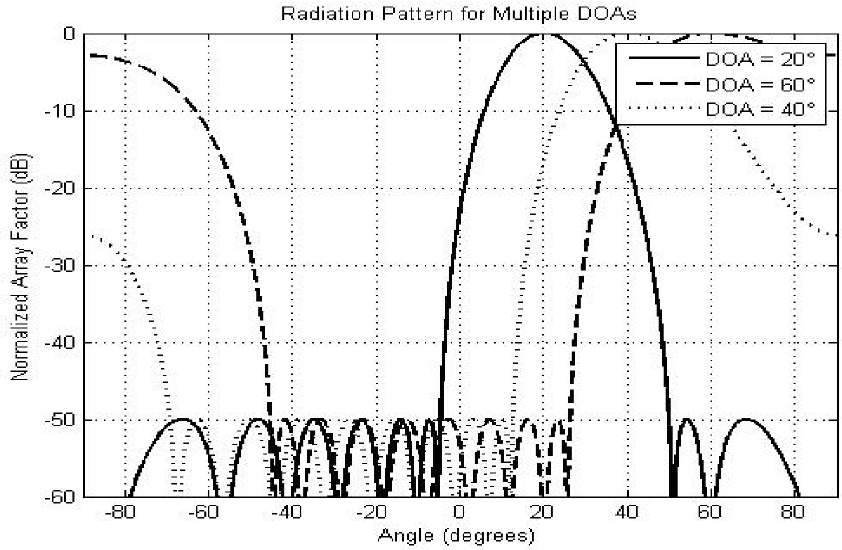

Figure 3: Radiation Pattern For DOA=20º,60º,40º

Table.2 Amplitude of each element

		Number of Element							
DOA	Element	1	2	3	4	5	6	7	8
20º,60º,40º	Amplitude	0.07	0.23	0.51	0.80	1.0	0.51	0.23	0.07

Table 2 shows the amplitude of each element of the antenna of DOA : 20,60º,40º. The excitation starts low at the outer elements (0.0703), increases toward the center (up to 1.0000), and then symmetrically decreases as you move toward the other side of the array. This pattern helps focus the radiation in a desired direction while keeping side lobes suppressed.

These values reflect the Chebyshev window's effect on tapering the amplitude, resulting in a radiation pattern that offers low side lobe levels and a focused main beam, enhancing the performance of your antenna array

Figure 3 shows the radiation patterns generated for two distinct DOAs: 50°,80º.Number of elements: 9 .The main lobes are clearly directed toward the desired angles, while the side lobes are minimized due to the application of Chebyshev amplitude tapering. The Chebyshev tapering used is 50dB.

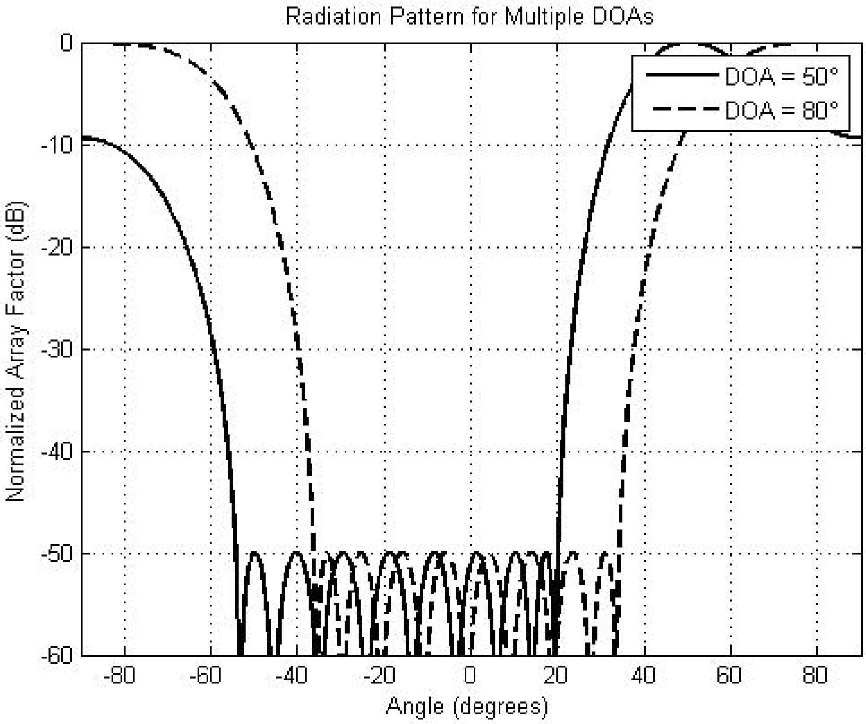

Figure 4: Radiation Pattern For DOA=50º,80º

Table.3 Amplitude of each element

Number of Element										
DOA	Element	1	2	3	4	5	6	7	8	9
50º,80º	Amplitude	0.12	0.31	0.58	0.83	1.0	0.83	0.58	0.31	0.12

Table 3 shows the amplitude of each element of the antenna of DOA : 50º,80º. The excitation values gradually increase from the outermost elements (0.1253) to the center (1.0000) and then symmetrically decrease again. This tapering ensures the radiation pattern is focused in the desired direction and that side lobes are minimized.The Chebyshev window used in this setup ensures the antenna array maintains a sharp main beam and low side lobe levels, optimizing the antenna for high-directivity applications.

Figure 4 shows the radiation patterns generated for three distinct DOAs: 40°, 60°, and 80°.Number of elements:9 The main lobes are clearly directed toward the desired angles, while the side lobes are minimized due to the application of Chebyshev amplitude tapering.The Chebyshev tapering used is 40dB.

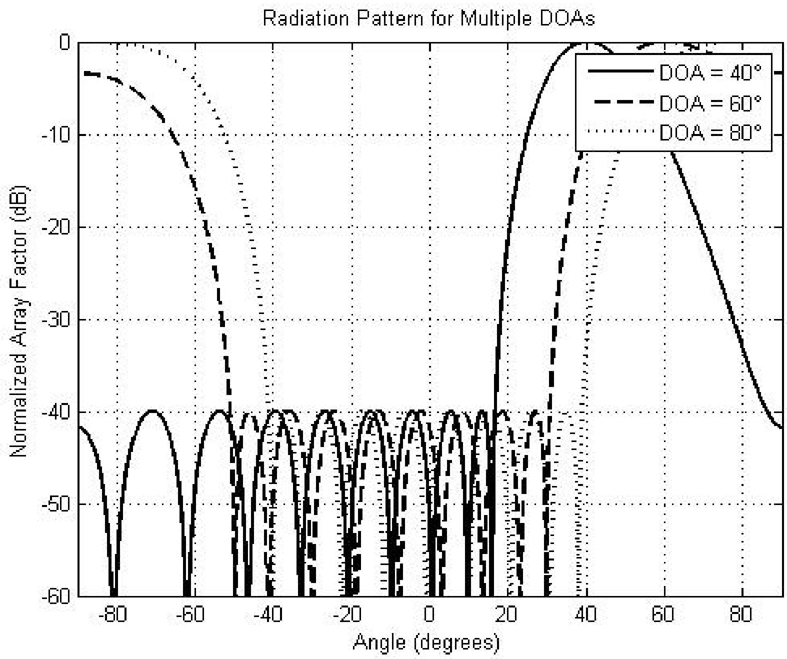

Figure 5: Radiation Pattern For DOA=40º,60º,80º

Table.4 Amplitude of each element

		Number of Element								
DOA	Element	1	2	3	4	5	6	7	8	9
40º,60º,80º	Amplitude	0.12	0.31	0.58	0.83	1	0.83	0.58	0.31	0.12

Table4 shows the amplitude of each element of the antenna of DOA : 40º,60º,80º.
The outer elements (1st and 9th) receive the least excitation (0.1253).The center elements (4th and 5th) receive the highest excitation (1.0000), ensuring a focused main lobe.The resulting radiation pattern features minimal side lobes and a narrow main lobe, which is critical for achieving high directivity andminimizing interference in communication and radar systems.This amplitude tapering technique helps achieve better performance by focusing energy in the desired direction and reducing unwanted radiation from side lobes.

4. CONCLUSION

This research presents an optimized amplitude excitation technique for side lobe suppression in smart and adaptive antennas, addressing a critical challenge in modern wireless communication systems. By systematically adjusting amplitude distributions across the antenna elements using Chebyshev tapering, the proposed method achieves a significant reduction in side lobe levels while maintaining high directivity and signal-to-noise ratio (SNR). Unlike conventional phase-only beamforming approaches, this method integrates amplitude-phase control, leading to improved beam steering accuracy and interference mitigation.

Simulation results confirm that the optimized radiation pattern effectively reduces unwanted radiation, thereby enhancing spectral efficiency andreliability. Furthermore, experimental validation using a prototype smart antenna system demonstrates the practical feasibility of this approach in real-world applications, including 5G networks, satellite communications, and radar systems. The study also highlights the impact of mutual coupling effects and adaptive beamforming techniques, reinforcing the importance of precise excitation control in phased arrays.

Overall, this research contributes to the development of high-performance, interference-resistant antenna systems capable of meeting the demands of next-generation wireless networks. Future work could explore machine learning-driven optimization, dynamic adaptation for real-time applications, and integration with massive MIMO systems to further enhance the adaptability and efficiency of smart antennas in complex wireless environments.

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