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Review Paper on Beamforming Technique Based on Smart Antenna Systems

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Abstract. *Beamforming technology within smart antenna systems is recognized as a crucial advancement in contemporary wireless communication, playing a substantial role in boosting network efficiency and capacity. Through the targeted steering of signals for transmission and reception to particular users or devices, beamforming diminishes interference while maximizing the utilization of existing bandwidth. This study discovers into the principles and applications of beamforming in smart antenna systems, emphasizing its influence on enhancing signal quality, coverage, and overall network efficiency. Through a comprehensive review of existing literature, it is observed that different researchers have proposed distinct approaches to address this objective, Therefore, it can be deduced that there is no singular approach present in this context. The manuscript investigates the obstacles linked to beamforming, including computational intricacy, hardware limitations, and the necessity for accurate synchronization. By conducting a thorough examination, this research highlights the revolutionary capacity of beamforming technology in enhancing intelligent antenna systems and influencing the trajectory of wireless communications recorded cracking and failure numbers.*

Keywords: *Beamforming; Smart antenna; adaptive arrays; adaptive algorithms; wireless communication.*

1. INTRODUCTION

Beamforming plays a pervasive role and is crucial for a variety of array processing applications including radar, sonar, acoustics, astronomy, seismology, ultrasound, and communications. Recent advances in mobile communications have led to the utilization of large arrays, high-frequency sensors, near-field signal recovery, and smart radio environments, thereby presenting intriguing and innovative signal processing challenges in beamforming. Smart antenna systems, characterized by their multi-element configuration, have propelled the demand for enhanced robustness, adaptable deployment, and simplified beamforming algorithms, alongside a focus on sophisticated signal processing methods customized to meet the evolving needs of specific applications.[1]

Smart antennas, a type of multi-element antenna, utilize intelligent signal combining techniques to enhance the efficacy of wireless systems by extending signal coverage, mitigating signal deterioration, suppressing unwanted signals, and augmenting the overall capacity of wireless networks.

Deep transfer learning techniques can greatly improve beamforming optimization for Intelligent Reflecting Surface (IRS) assisted MISO systems. These techniques make use of sophisticated algorithms to optimize beamforming, which is complicated because it requires extra hardware for both active and passive beamforming [2].

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Combining multi-agent deep reinforcement learning (MADRL) with sequential convex approximation (SCA) is one way to address those issues. That approach can guarantee efficient sensing performance and enhance communication. Furthermore, when it is used to facilitate communication between a multi-antenna base station (BS) and its clustered multi-antenna users, the challenges can be used instead of IRS [3].

Furthermore, by simultaneously optimizing the transmit beamforming matrices of the BS, the receive beamforming matrices of the users, and the phase shifts of the IRS, the task can be made simpler by maximizing the sum rate of all users. To reduce the difficulties, a block diagonalization technique can be used to represent the beamforming matrices of the IRS phase shifts and the users by the BS [3].

2. OVERVIEW OF BEAM FORMING

Beamforming enhances the signal quality and capacity of communication systems by carefully controlling the transmission energy directed towards desired users while minimizing interference. This technique is particularly effective in efficiently utilizing higher frequency bands, where resources are often scarce [1, 2, 3].

Sophisticated communication systems employ dynamic beamforming to steer signal energy towards specific users or areas, boosting signal strength and quality while suppressing interference. This capability is crucial for optimal utilization of the limited spectrum.

Beamforming improves wireless communication technology by directing energy from multiple antennas on a receiver, resulting in better signal quality, reduced interference, and higher data transfer rates without increasing broadcast power [1].

A directivity control element, such as a phased array antenna, utilizes matrix circuits to introduce phase shifts in output signals, thereby improving communication system design. Beamforming devices employ control circuits to calibrate the phase or amplitude of input signals, enabling the formation of higher frequency transmission signals for enhanced system performance using multiple antenna elements.

Beamforming is a valuable technique in communication systems, especially vehicle-to-vehicle communication, as it focuses energy towards specific receivers, improving signal quality and system efficiency [1,4].

3. SMART ANTENNA SYSTEM

3.1. LITERATURE REVIEW

Das (2008) The paper provides a detailed account, comparative evaluation, and practical implications of different reference signal algorithms, alongside blind adaptive algorithms tailored for smart antenna systems. A comprehensive simulation investigation into beam patterns and learning behaviours has demonstrated the effectiveness of the proposed methodology from an applied perspective.[2]

Shaukat et al (2009) demonstrated through simulation results that algorithms such as Recursive Least Squares (RLS) and Least Mean Squares (LMS) are optimal for beamforming, specifically in the direction of the desired user. However, these algorithms exhibit limitations in terms of interference rejection. Conversely, the Constant Modulus Algorithms (CMA) displays an acceptable execution in beamforming and suggests enhanced interference rejection capabilities. However, the Bit Error Rate (BER) ranges its maximum when a single antenna element is employed in CMA [3].

Wang and Song (2010) announced a novel broadband minimum variance distortion-less response beamforming technique exploiting time-domain signals for smart antennas. This technique includes the creation of complex weights through the Hilbert transform, follow-on in the rapid achievement of a consistent optimal solution. Within a mobile communication system, this algorithm displays excellent performance [4].

Li and Wang (2011) anticipated that the integration of Field-Programmable Gate Array (FPGA) and Digital Signal Processing (DSP) allows the employment of the constant modulus algorithm (CMA) with effortlessness. Afterward, a system for beamforming, FPGA+DSP-based, was established in agreement with this method. Furthermore, the orientation diagrams for the desired antenna were provided. Concurrently, an investigation was directed at the convergence rate and numerous performance metrics of the aforementioned algorithm. The results indicated the practicability of the proposed process [5].

Imtiaj and colleagues (2012) claim the evolution of fixed weight beamforming basics (FWBB) in a historical context, alongside the advancements in adaptive arrays. Subsequently, a comparative analysis is conducted between the efficiencies of two adaptive algorithms, namely the Least Mean Square (LMS) and Sample Matrix Inversion (SMI) [6].

Reddy and Devi (2013) conducted a study on a Smart antenna that exhibits a direct main lobe, characterized by increased gain, towards the angle of arrival (AOA) of the user, and direct nulls in directions opposite to the main lobe or towards the AOA of interfering signals. To achieve this, the Kernel Least Mean Square (KLMS) Algorithm, known for its adaptability, is utilized to compute the optimal weight vectors required to construct phased beams. This method aims to report the limitations existing in the Mean Square Error (MSE) of current algorithms, at last enhancing the robustness of the smart antenna system [7].

Rehman and Mujahid (2014) studied the management of intelligent antenna radiation patterns via beamforming algorithms. This academic work focuses on the result of perfect beamforming strategies in upgrading data speed rates and scope areas inside cellular communication networks. Specifically, the approach including Multiple Sidelobe Canceller (MSC) and Minimum Variance Distortion Less Response (MVDR), in addition, Minimum Mean Square Error (MMSE) is studied. The outcome exposes the power of the MMSE beamformer in dealing with the issue of Non-Line of Sight (NLOS) fading, considering that the MVDR beamformer exhibits robust attainment in Line-of-Sight (LOS) fading conditions. Further, the MMSE beamformer surpasses different method with its mainly limited Half Power Beamwidth (HPBW) and Null-to-Null Beamwidth (NNBW) [8].

Waghmare et al (2015) supervised an academic study on beamforming system, for instance, the Linear Constraint Minimum Variance (LCMV), as well as, Minimum Variance Distortion-less Response (MVDR), along the motivation of strengthening data rates, capacity, null controlling, and range in cellular systems terminate the procedure of diverse beamforming manner. The summary of the analysis exhibits that, beyond different system Attributes, the MVDR technique exceeds the LCMV process. Surely, the MVDR beamforming system Addresses the objection of multi-path fading by offering the multipath signal to intensify the power of the desired signal [9].

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Zhou and Yang (2016) recommend an innovation adaptive beamforming approach to checking and upgrading a module vulnerable to the prediction of the gradient vector, and that was afterward advantageous to a Uniform Linear Array (ULA). The exceptional composition of the algorithm was later on measured opposed to the conventional Least Mean Square (LMS) algorithm to assess its capability. Simulation results validate the extraordinary performance of the new algorithm. The intention of this search is to upgrade the coverage area and capacity of communication systems by enriching the beamforming design [10].

Rathore and Panda (2017) propose algorithms are adapted by intelligent antenna networks which are adaptive algorithms that have been used to measure the Sophisticated weight quantities in a way that the initiated lobe is oriented adjacent to the nominate user, at the same time, placing the null in the course of the objectionable user. This investigation presents an experienced inspection of the least mean square (LMS). Based on the beam pattern, the LMS algorithm adopts a decision feedback equalizer (DFELMS), in addition, the least mean square algorithm combines data reuse (DRLMS). By contrast, the DRLMS algorithm exhibitions Premium performance scale up t to the DFELMS and LMS algorithms [11].

Guerra Gómez et al (2018) initiated Radio Frequency Identification (RFID) structures which is an exceptional antenna processing method. The inquiry of Space Time Adaptive Processing (STAP) elaborates the work of digital down converters and IQ beamformer, as well as, the sophisticated Least Mean Square (LMS) algorithm, were exactly assembled and tested on the Xilinx z7020 Field Programmable Gate Array (FPGA) Principle. The execution of the system appeared to be estimable in relation to the Bit Error Rate (BER) under the circumstances wherever the Signal Noise plus Interference Ratio (SNIR) surpasses 1 dB, inside a Medium measured by a Signal Noise Ratio (SNR) of 7 dB [12].

Biswas et al. (2019) studied the Particle Swarm Optimization (PSO) algorithm that is a new beamforming technique and its resultant application on Xilinx Virtex4 Field-Programmable Gate Arrays (FPGA) society, with efficiency supportive likened to the present beamforming methods operating by smart antennas. the Dolph–Chebyshev polynomial and Cosine function are collecticted in the research. In addition to the mentioned above, the system plan comprised the occupation of proper coordinate Rotation Digital Computer (CORDIC) and Finite State Machine with Datapath (FSMD) representation and building blocks as material elements. These results, in addition, validate the capability of this algorithm in contrast to the existing beamforming systems of smart antennas [13].

Nalband and colleagues (2020) considered millimeter wave massive MIMO system and emphasized their study on the reducing the usage of power and the establishment of the greatest suitable amount of RF chains. In this research, the highest quantity of antenna elements is calculated by taking into consideration the precise resolution of Analog-to-Digital Converters (ADCs) while testifying that reception property is not negotiated. An extraordinary improvement in execution as a Result was achieved after the submission of the planned algorithm as opposed to classical and random antenna choice techniques [14].

Rahmad et al. (2021) managed an experiment in purpose to settle the useable adaptive algorithm to achieve the predicted beamforming system. The influence of the normalized least mean square (NLMS) algorithm on the shapes of step size parameters is the main intention of this investigation, which plays a pivotal role in operating the anticipated minimum square error (MSE) value and the preparation of nulling beam radiation designs in smart antennas for interfering lessening.

Therefore, improving the separation among the spaced elements is the clear goal to increase in the number of nulling applied. Positioning the nulls along the interference source, the interference is professionally overcome, with the most critical interference level attaining around -90 dB when using the smallest step size present [15].

Samal and colleagues (2022) achieved a search by employing a hybrid optimization algorithm that was established by integrating a boosted iteration of the whale optimization algorithm (IWOA) and an

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improved sine cosine algorithm into the purpose of studying adaptive beamforming in a linear antenna array. The algorithm's resilience is confirmed by the enhanced performance accomplished through the decrease of bit rate, transmitted power, and beamforming across changeable numbers of array elements exploitating the hybrid optimization process [16].

Komeylian and Paolini (2023) executed the utilization of the LCMV beamformer within the cylindrical antenna array to achieve a delicate resolution and precision in the reception of signals. The employment of the LCMV beamforming technique within the cylindrical antenna array validates a remarkable efficacy of 90.34%, alongside a substantial Signal-to-Interference Ratio (SIR) of 2.257 (dB). In this specific scenario, the time domain calculation of the cylindrical antenna array has authenticated that the peak voltage amplitude escalates to 800 (volt) within the IEEE 802.11x frames [17].

Jiang et al (2024) presented an adaptive information meta-surface for the twin of intelligent sensing and wave management. Precisely, the objective is to accomplish intelligent target localization and adaptive beam tracking. This meta-surface encompasses an array of meta-atoms, each prepared with two PIN diodes and a sensing-channel building. These components simplify polarization-insensitive and programmable beamforming and sensing. Through management of the PIN diode's state, each meta-atom displays a 1-bit phase response within the selected frequency range, preserving a sensing loss exceeding -10 dB for both "ON" and "OFF" states. Experimental results align well with numerical simulations and theoretical calculations [18].

Numerous algorithms, comprising Recursive Least Squares (RLS), Least Mean Squares (LMS), and Constant Modulus Algorithm (CMA), have been inspected for their effectiveness in beamforming and interference mitigation within the framework of smart antenna technology, as demonstrated by this review of literature on beamforming technology in smart antennas. Besides, it has been experimental that the employment of broadband beamforming techniques including the Hilbert transform shows superior performance in the domain of mobile communications. The application of CMA-based beamforming on FPGA and DSP systems has been revealed to enhance performance by permitting rapid convergence and efficient management. A variety of research activities have explored adaptive algorithms such as Kernel Least Mean Squares (KLMS) and numerous adaptations of LMS, all intended to develope the performance of smart antennas by steering the main lobe to the planned user while guiding nulls to interfering signals. Recent policies have combined optimization algorithms for example whale optimization and sine cosine algorithms to develop adaptive beamforming in antenna arrays, with an emphasis on enhancing strength while reducing both bit rate and power transmission. Moreover, the application of adaptive information meta-surfaces has been presented for intelligent sensing and beamforming functions, joining meta-atoms with adaptable phase responses to boost target localization and beam tracking.

An innovative and stimulating path in beamforming research contains its application in intelligent sensing and wave management. Across the dynamic alteration of beam patterns, these systems present the ability to sense their surroundings and direct electromagnetic waves in real time. This progress shows great possibility for advancement in fields like smart radar, self-interfering communications, and metamaterials. These progressions highlight the continuous accomplishments to perfect beamforming methodologies to

deliver to the advancing requirements of modern communication systems, with a robust importance on discriminating performance, flexibility, and efficiency.

4. CONCLUSIONS

In this paper, a comprehensive inspection is offered of the Beamforming Algorithm applied in smart antenna systems, with a precise focus on various techniques and the challenges they involve. The analysis discovers a range of algorithms for instance LMS, RLS, and CMA, evaluating their efficiency in terms of beamforming and interference mitigation. Additionally, it is observed that Beamforming plays an essential role in boosting communication systems by improving signal quality, extending range, and optimizing network functioning through the targeted transfer of signals to definite users. Current research endeavors are devoted to the development of beamforming techniques, with a specific emphasis on accomplishing superior performance, rigidity, and efficiency to supply the evolving necessities of modern communication systems. The appearance of novel applications for beamforming technology, such as Adaptive information meta-surfaces for intelligent sensing and wave manipulation, signifies a promising path for additional exploration. Eventually, this review effectively highlights the significance of beamforming in smart antenna systems, shedding light on the repeated progress within this field.

The phase shifts of the IRS, It is noteworthy to point out that this joint optimization is of paramount important for maximizing the sum rate of all users engaged in the communication process. Used a block diagonalization (BD) method to express the beamforming matrices using the IRS phase shifts. This approach makes the optimization problem easier, which means that the solution process becomes easier as well. Based on the analysis of the results, it can be concluded that IRS technology has significant potential in improving the performance of MIMO networks and expanding the further exploration of the effectiveness of future IRS aided communication system and its practical application.

REFERENCES

[1] Elbir, A. M., Mishra, K. V., Vorobyov, S. A., & Heath, R. W. (2023). Twenty-five years of advances in beamforming: From convex and nonconvex optimization to learning techniques. IEEE Signal Processing Magazine, 40(4), 118-131.

[2] Das, S. (2008, November). Smart antenna design for wireless communication using adaptive beam-forming approach. In TENCON 2008-2008 IEEE Region 10 Conference (pp. 1-5). IEEE.

[3]

[4] Shaukat, S. F., Hassan, M., Farooq, R., Saeed, H. U., & Saleem, Z. (2009). Sequential studies of beamforming algorithms for smart antenna systems. World Applied Sciences Journal, 6(6), 754-758.

[5] Wang, L., & Song, Z. (2010, September). Study on Broadband Adaptive Beamforming Method for Smart Antenna. In 2010 6th International Conference on Wireless Communications Networking and Mobile Computing (WiCOM) (pp. 1-4). IEEE.

[6] Li, D., & Wang, Y. (2011, April). Study of smart antenna beamformer based on constant modulus algorithm. In 2011 Fourth International Conference on Information and Computing (pp. 178-180). IEEE.

[7] Imtiaj, S. K., Misra, I. S., & Biswas, R. (2012, December). Performance comparison of different adaptive beamforming algorithm in smart antennas. In 2012 5th International Conference on Computers and Devices for Communication (CODEC) (pp. 1-4). IEEE.

[8] Reddy, N. G., & Devi, K. R. (2013). Smart antennas adaptive beamforming through statistical signal processing techniques. International Journal of Research in Computer and Communication Technology, 2(8), 400-405.
[9] Rehman, A., & Mujahid, U. (2014). Performance trade-offs among optimized beamforming techniques for smart antenna system. Bahria University Journal of Information & Communication Technology, 7(1), 27.
[10] Waghmare, S., Gotarne, N., Botre, R., & Maske, K. G. (2015). Beamforming Smart Antenna LCMV & MVDR Algorithm. International Journal of Advanced Research in Computer Engineering & Technology (IJARCET), 4(3), 1023-1026.
[11] [Zhou, Y., & Yang, X. (2016, December). A novel adaptive beamforming algorithm for smart antenna system. In 2016 12th International Conference on Computational Intelligence and Security (CIS) (pp. 522-525). IEEE.
[12] Rathore, A., & Panda, D. K. (2017, August). DRLMS, DFELMS, LMS adaptive beamforming algorithms for smart antenna system. In 2017 International Conference on Information, Communication, Instrumentation and Control (ICICIC) (pp. 1-5). IEEE.
[13] Guerra Gómez, R., Viqueira Bernal, S. L., & Marante Rizo, F. (2018). Space Time Adaptive Processing for Radio Frequency Identification Smart Antenna Systems. Ingeniería Electrónica, Automática y Comunicaciones, 39(3), 89-104.
[14] Biswas, R. N., Saha, A., Mitra, S. K., & Naskar, M. K. (2019). Realization of PSO-based adaptive beamforming algorithm for smart antennas. Advances in nature-inspired computing and applications, 135-163
[15] Nalband, A. H., Sarvagya, M., & Ahmed, M. R. (2020). Power scaling and antenna selection techniques for hybrid beamforming in mmWave massive MIMO systems. International Journal of Electronics and Telecommunications, 66.
[16] Rahmad, H., Givy, D. R., Ninik, S. L., Andrew, G. M., & Hetty, F. (2021). Optimization of Normalized Least Mean Square Algorithm of Smart Antenna Beamforming for Interference Mitigation. In J. Phys.:Conf. Ser (Vol. 12085).
[17] Samal, S., Sahoo, H. K., & Kumar Das, P. (2022). Hybrid Optimization Approach for Adaptive Beamforming in Smart Antenna System. In Next Generation of Internet of Things: Proceedings of ICNGIoT 2022 (pp. 573-584). Singapore: Springer Nature Singapore.
[18] Komeylian, S., & Paolini, C. (2023, March). Performance Evaluation of Implementing LCVM Beamformer for Cylindrical Antenna Array in Smart Array Antenna Applications. In 2023 17th European Conference on Antennas and Propagation (EuCAP) (pp. 1-5). IEEE.
[19] Jiang, R. Z., Ma, Q., Gu, Z., Liang, J. C., Xiao, Q., Cheng, Q., & Cui, T. J. (2024). Simultaneously intelligent sensing and beamforming based on an adaptive information metasurface. Advanced Science, 11(7), 2306181.
[20] Songling, Zhang., Zhaohui, Yang., Mingzhe, Chen., Danpu, Liu., Kai-Kit, Wong., H., Vincent, Poor. (2024). 3. Beamforming Design for the Performance Optimization of Intelligent Reflecting Surface Assisted Multicast MIMO Networks. IEEE Transactions on Wireless Communications, Available from: 10.1109/twc.2023.3297732.
[21] Adit, Jain., Rimalapudi, Sarvendranath., Salil, Kashyap. (2024). 2. Joint Antenna Selection and Beamforming for an IRS Aided IoT System. Available from: 10.1109/wcnc57260.2024.10570704.

Al-Furat Journal of Innovations in Electronics and Computer Engineering (FJIECE)
ISSN -2708-3985

[22] Yanping, Zhou., Fang, Deng., Shidang, Li. (2024). 4. Jointly Active/Passive Beamforming Optimization for Intelligent-Reflecting Surface-Assisted Cognitive-IoT Networks. Electronics, Available from: 10.3390/electronics13020299.

[23] Fei-Hu, Zhao., Wanming, Hao., Xiaobei, You., Yi, Wang., Zheng, Chu., Pei, Xiao. (2024). 5. Joint Beamforming Optimization for IRS-Aided THz Communication With Time Delays. IEEE Wireless Communications Letters, Available from: 10.1109/lwc.2023.3319347.

[24] Q., Zhai., Limeng, Dong., Wei, Chen., Yong, Li., Peng, Liu. (2023). 6. Joint Optimization for Active IRS-Aided Multicluster NOMA Systems. IEEE Systems Journal, Available from: 10.1109/jsyst.2023.3292375.

[25] Subba, Amin., Javaid, A., Sheikh., Mehboob-ul-Amin., Bilal, A., Malik. (2023). 10. A deep reinforcement learning for energy efficient resource allocation Intelligent Reflecting Surface (IRS) driven Non-Orthogonal Multiple Access Beamforming (NOMA-BF). Physical Communication, Available from: 10.1016/j.phycom.2023.102148.