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Interference Mitigation using Adaptive Digital Beamforming for 5G Applications

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Abstract - *Present and upcoming wireless communication technologies requires high signal to noise ratio, gain, and signal intensity in order to reduce interference. Modern communication relies heavily on adaptive digital beamforming to improve desired signal reception while reducing sidelobe and interference effects. This study proposes a method for suppressing sidelobes, interference and to mitigate noise using adaptive digital beamforming for 5G applications based on the Minimum Variance Distortionless Response (MVDR) algorithm specially for the operating frequency range of 3.5GHz. The adaptive digital beamforming employing the MVDR algorithm will be extremely important in providing the seamless connection and variety of services that 5G promises to bring as it continues to develop and is more extensively adopted. The suggested solution takes advantage of the MVDR algorithm's adaptive properties to dynamically change the weights of an antenna array, altering the radiation pattern to direct the primary beam towards the desired signal source while dampening unwanted signals. The MVDR adaptive beamforming algorithm is applied towards the desired signals at baseband mainly to suppress sidelobes by introducing nulls in the direction of interference, which helps to reduce the sidelobes, mitigates interference and noise.*

Key Words: *Adaptive Beamforming, MVDR algorithm, Interference, Sidelobes,5G Communication*.

1.INTRODUCTION

The demand from customers for an effective communication system to support the seamless operation of daily activities and at work has accelerated the development of telecommunication technology. For instance, the transition from the 2nd Generation (2G) to the 3rd generation (3G) to the 4th generation (4G) is intended to enable the function of data transmission over the internet network on a mobile station (MS) device. The development and transition between one network technology from one generation to the next is intended with the aim of covering up shortcomings and developing technology from its predecessor generations [1]. More than one communication device is now connected to the network by some telecommunication service subscribers. In order to handle every communication activity from the user to the central network without any problems, we obviously need a data transmission technology system. Fifth Generation (5G) technology has been used to address this problem [2].

Several techniques have been developed for the data communication system to enhance signal transmission performance, raise the SINR, and adjust other associated parameters. In that case, the signal quality can be assessed by making reference to the antenna choice and the highly accurate beam strength estimation. Users can communicate utilizing the signal band in the 5G communication-based networking system that is available for data transmission at increased speeds from antenna signal propagation [3]. It is necessary for communication systems that are unable to connect with the user module to strengthen the signal by carefully choosing their antenna array. This can be done by using an optimization method to choose the optimal antenna and figure out the best DOA (Direction of Arrival) path to the device for higher SINR. By identifying the antenna parameters, the communication model's signal strength is improved [4]. The optimal choice of Direction path from the overall structure in estimated parameters was found using optimization methods. Additionally, it estimates the number of antennas with DOA characteristics that are ready to connect to the device and are distributed to users with the best antenna capacity match [5].

High data rate, high SNR, high signal integrity, and high bandwidth are essentially the end goals of a communication system network in current and future wireless communication technology. With an increase in the number of users in a communication system network, these characteristic performances decline. 5G technologies are being adopted to overcome these issues, and it is anticipated that they will significantly expand the use of the current communication infrastructure [6]. Additionally, it will enable connectivity between people and machines (the Internet of Things), enabling applications for remote healthcare, autonomous self-driving cars, and virtual and augmented reality (VR/AR), and more. By adopting spatial diversity, massive antenna array deployment also aids in reducing some of these issues and improving data throughput in wireless communication channels. Since the antenna array signals are integrated at the transceiver in mmWave application, the adoption of beamforming technology significantly enhances the channel propagation characteristics as well as the coverage area [7].

Adaptive beamforming is the process of forming the antenna beam pattern using a Digital Signal Processor (DSP) algorithms. Because separate RF chains are needed for each antenna element, hardware complexity, excessive power consumption, and high overhead costs provide the biggest obstacles to the implementation of completely digital beamforming transceiver systems. Due to these Digital Beamforming Forming (DBF) restrictions, analogue and hybrid beamforming are still highly appealing. In recently examined circumstances, several doable solutions have been put out to handle some of these difficulties [8].

Applying beamforming techniques is one of the methods utilized in 5G technology to improve system dependability, Using the technique of Adaptive Beamforming, antennas will be capable of focusing the beam on the chosen mobile target Finding or applying a weighting value to each element of the array input in order to guide the main beam (also known as main lobe, which is another name for signal of interest) in the desired signal direction is known as adaptive beamforming [10]. Thus, electronic beam by directing eliminates the requirement for the components to rotate mechanically during the process. The system can typically be constructed from an array of sensors (such as microphones, speakers, or antennas), each of which is connected to an amplifier unit and/or a phase shifter that is controlled by a signal processor. As a result, a signal processing algorithm is needed to determine the proper weighting values. It is meant for the system to function at its best [11].

2. LITERATURE SURVEY

In [1] authors proposed the adaptive beamforming technique for 5G communication with an operating frequency of 2.4GHz using a linear array antenna at reception end, the authors used Least Mean Square (LMS) adaptive algorithm to perform beamforming for 5G communications.

In [2] authors proposed machine learning technology for performance evaluation of adaptive beamforming when it is deployed to 5G using massive multiple input multiple output cellular networks in order to increase spectral efficiency and energy efficiency.

In [3] the authors proposed solution that can mathematically achieve constructions between the S ports of the base station (BS) and the U ports of the receiving antenna array, making it possible to measure the throughput of a terminal with an adaptive beamforming array as per the air interface standards, using a newly developed 4 × 4 5G MIMO device. The outcomes perfectly capture how the suggested solution performs in real-world operating scenarios.

In [4] authors proposed the adaptive beamforming algorithm named Recursive Spectral Classification(RSC) for 5G networks, here RSC adaptive beamforming technique is used on smart antenna propagation mainly to improve the coverage area for 5G networks.

In [5] authors proposed the adaptive beamforming technique at reception end for 5G uplink communication system. The proposed adaptive beamforming algorithm is Salp-Bird Swarm Optimization(S-BSO), which is the combination of both Shark Smell Optimization Algorithm(SSO) and Bird Swarm Algorithm (BSA), here the authors have analyzed the performance of each algorithm in terms of Bit Error Rate (BER), Signal to Noise Ratio(SNR).

In [6] authors proposed performance analysis of adaptive beamforming algorithms by considering convergence rate as a major factor for 5G applications at the reception end. The adaptive beamforming algorithms used by authors are Least Mean Square(LMS), Normalized Least Mean Square(NLMS), Leaky Least Mean Square(Leaky-LMS), Sign-Leaky Least Mean Square (Sign-Leaky LMS).

In [7] authors have done comparison between two different adaptive beamforming algorithms namely LMS and MVDR algorithm, based on number of antenna elements and antenna element spacing to signal quality using MIMO (Multiple Input Multiple Output) for Millimeter Wave 5G Applications.

In [8] authors, proposed Conventional beamforming method named Kaiser Window method and suppressed side lobes for a Massive MIMO Structure using the 3D beamforming method.

In [9] the authors proposed a sidelobe canceller null widening method that is computationally effective. This technique, a covariance matrix taper-based technique, widens the acute null by introducing artificial interferences into pictures. The suggested method is more efficient than current methods in terms of calculation costs and can deliver satisfactory performance.

In [10] the authors proposed current sheet array (CSA) subarrays' grating lobe angular position is initially analytically retrieved in this research. The grating lobes of the subarrays were then nulled using the suggested technique by adjusting the CSA elements' weights. The results of the simulation show that the side lobe levels (SLLs) and peak side lobe ratio (PSLR) in the power pattern achieved by the suggested approach are superior to the earlier methods, also known as product and min processors.

In [11] authors proposed adaptive beamforming algorithms, evaluated and compared with conventional beamforming technique at reception end mainly to reduce interference by placing nulls in the direction of interference signal and to obtain mainlobe in the desired signal direction, authors have evaluated the side lobe level and the main lobe level for each beam, authors had used conventional beamforming technique to form a beam. Later they have compared this conventional beamforming technique with three different adaptive beamforming methods by the help of adaptive beamforming algorithms, they are MVDR, Recursive Least Square(RLS) and Sample Matrix Inversion(SMI).

3. METHODOLOGY

3.1 Conventional Beamforming

By properly weighing the signals received at the various array members, the conventional beamforming method produces a beam that points in the direction of the intended signal. The array weights are commonly chosen in traditional beamforming to maximize the strength of the intended signal at the beamformer's output.

3.2 Adaptive Beamforming

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In antenna array processing and signal processing applications, MVDR adaptive beamforming is a method used to boost the intended signal of interest while reducing interference and noise. It is a type of adaptive beamforming that instantly modifies an antenna array's weights in response to signals being received. The calculated covariance matrix of the interference and noise, along with the received signals, are used to iteratively update the array weights in MVDR adaptive beamforming. The beamformer's output power is reduced throughout the weight update process while still maintaining distortion-free responsiveness to the target signal.

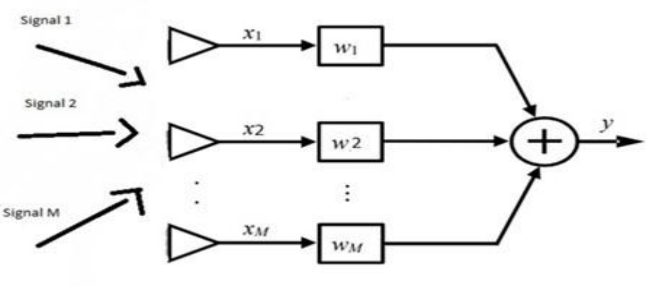

Fig -1: Beamformer block diagram

Let the signals transferred in the beamformer be,

signal= {1,2, ...M}

And the total received signal represented as,

x= {1,2, ...M}.

Let the total received signal be $X_T(t)$, which includes desired signal Xs(t) and interference signal Xi(t) and noise signal Xn(t), the received signal XT(t) can be represented as,

$X_T(t)=\sum_{s=1}^{S}{}^{*}Xs(t)\, a(\theta s, \Phi s)+\sum_{i=1}^{I}{}^{*}Xi(t)\, a(\theta i ,\Phi i)+Xn(t)$ ...(1)

Where θ is the azimuth angle and Φ is the elevation angle, and a is the steering vector which is defined as,

$a(\theta,\Phi)=[1,e^{-jqd\sin(\theta)\sin(\Phi)},e^{-jq2d\sin(\theta)\sin(\Phi)},......,e^{-jq(L-1)d\sin(\theta)\sin(\Phi)}]$(2)

Where q is wavenumber defined as,

$q=2\pi/\lambda$ ....(3)

λ is wavelength of received signal and d is interelement spacing, L represents number of antenna elements,

The weight vector equation for conventional beamformer becomes,

$w(t+1) =w(t)+ \mu[p(t)-Ry(t)w(t)]$ .... (4)

$w(t)=a/||a||$ ....(5)

$Ry=X_T(t)X^H (t)$ ....(6)

μ is the step size parameter.

For the Adaptive MVDR The covariance matrix, Ry is given below,

$Ry= \sigma^2{}_s\, a(\theta s, \Phi s)\, a^H(\theta s, \Phi s)+ \sum_{i=1}^{I}{}^{*}\ \sigma^2{}_i\, a(\theta i, \Phi i)\, a^H(\theta i, \Phi i)+$

$\sigma^2 n\ IdL$ ....(7)

$Rs= \sigma^2 s\, a(\theta s, \Phi s)\, a^H(\theta s, \Phi s)$ ....(8)

$Ri+n= \sum_{i=1}^{I}{}^{*}\, \sigma^2{}_i\, a(\theta i, \Phi i)\, a^H(\theta i, \Phi i)+ \sigma^2{}_n\, IdL$ ....(9)

IdL is LXL identity matrix,

MVDR weight vector that gives the solution as per the following formula,

$W_{MVDR}= a(\theta s, \Phi s)R^{-1}y/a^H(\theta s, \Phi s)\, R^{-1}y\, a(\theta s, \Phi s)$ ....(10)

Finally, the SINR is defined as the ratio of the average power of the desired signal divided by the average power of the undesired signal for Adaptive MVDR and SINR for conventional is given below,

$Adaptive\_SINR = w^H R_S w/w^H R_{i+n} w$ ....(11)

Where w is weight vector of Adaptive MVDR beamformer, Rs desired signal covariance matrix and Ri+n is covariance matrix of interference and noise.

$Conventional\_SINR =(|w^H a|\hat{}2)/(\sigma_n{}^2)$ ....(12)

w is the weight vector of the conventional MVDR beamformer, a is the steering vector representing the desired signal direction, $\sigma_n{}^2$ is the noise power.

4. RESULTS

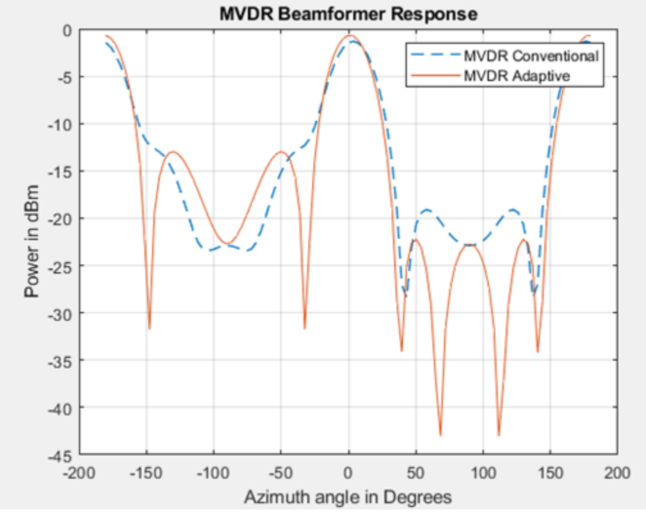

Fig -2: Radiation pattern produced respectively by conventional MVDR and Adaptive MVDR

From figure 2 compare to conventional MVDR, adaptive MVDR suppressed sidelobes efficiently, where desired signal location for both method is zero degree, the antenna elements considered for both cases is L=4.

Table -1: MVDR performance analysis table

Parameters	MVDR Conventional Beamforming	MVDR Adaptive Beamforming
Side Lobe Level (dB)	-17.7	-21.5
SINR (dB)	55.3	57.8

From table 1, compared to conventional MVDR, adaptive MVDR suppressed Side Lobe Level by 3.8dB and Signal to Noise plus Interference Ratio increased to 2.5dB.

Table -2: Simulation Parameters

Parameters	Values
Antenna array configuration	Uniform Linear Array(ULA)
Antenna type	Isotropic Antenna
Carrier frequency	3.5 GHz
Number of antenna elements	4
Antenna elements spacing	λ/2
Interference angle	60 degree

5. CONCLUSION

MVDR algorithm-based adaptive digital beamforming technology shows, significant promise for upgrading 5G communication systems. Higher data speeds, greater spectrum efficiency, and improved connection dependability are requirements of the 5G era and can be accomplished by employing effective and adaptive beamforming techniques. The MVDR-based beamforming technique demonstrates robustness, adaptability, and reliability in a dynamic and quickly changing wireless communication environment. It is ideal for 5G real-world applications because it can manage changes in the propagation channel, interference sources, and user mobility. The calculations and practical results have demonstrated that, in terms of suppressing side lobe level, and successfully rejecting interference, and received higher SINR in adaptive beamforming compared to Conventional beamforming and compared to the MVDR-based adaptive digital beamforming methodology outperforms conventional fixed beamforming method. In 5G communication systems, this performance boost directly correlates to better spectrum efficiency, expanded coverage, and improved connection reliability. Adaptive digital beamforming employing the MVDR algorithm in 5G communication is a critical enabler for realizing the full potential of this game-changing technology, and it has enormous potential to influence the development of wireless communication systems in the future.

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