Implementation of Beamforming Techniques for Upcoming Wireless Communications

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Abstract - *Present generation of cellular communications does not meet the data requirements of users as the number of users is increasing exponentially .In order to meet the increasing demand of users a high data rate signal is to be provided.In order to accomplish this goal a high frequency wave is created through mm wave antennas in combination with beamforming technology. Beamforming techniques provide high gain, interference mitigation and spatial multiplexing. Beamforming designs for cellular communications has received a good deal of interest in the research field due to diversity gains. In this paper a performance comparison of analog, digital and hybrid beamforming techniques are demonstrated.*

Key Words: CSI, MIMO, adaptive beamforming, conventional beamforming , hybrid beamforming, MSE (mean square error)

1. INTRODUCTION

Beamforming is a technique of producing high power beam in the direction of desired user while producing nulls in the direction of interferers. It is also referred to as directional signal transmission and reception. Present era is 4th generation of mobile networks. It is presumed that the forthcoming 5th generation of cellular communications will provide a data rate of 10 gbps. This high data signalling rate can be accomplished by various techniques. However to get such a high data signalling rate, there is requirement of a high frequency wave. Massive mimo beamforming can be employed to achieve such a high data rate with high frequency wave to be brought with mm wave antennas. Broadly speaking beamforming techniques can be categorized into conventional beam forming and adaptive beamforming .In conventional beamforming an aerial array has a fixed set of patterns which can be employed while transmission and reception of signals .However that is not the case with adaptive beamforming which dynamically change the array pattern in the real time. But in case of conventional beamforming we are well aware about the channel state information (CSI) of a communication link while that is not the case with adaptive beamforming[3]. So an intermediate technique is to be used in order to achieve both goals i,e CSI as well dynamic array pattern .That technique is referred to as hybrid beamforming[3].An example of radiation pattern in case of beamforming is shown in fig-1.

In this paper a performance comparison between different beamforming techniques will be simulated for upcoming wireless communications. Also one of the promising techniques to get 5g of cellular communications implemented is through full duplex systems using multiple number of antennas[2].

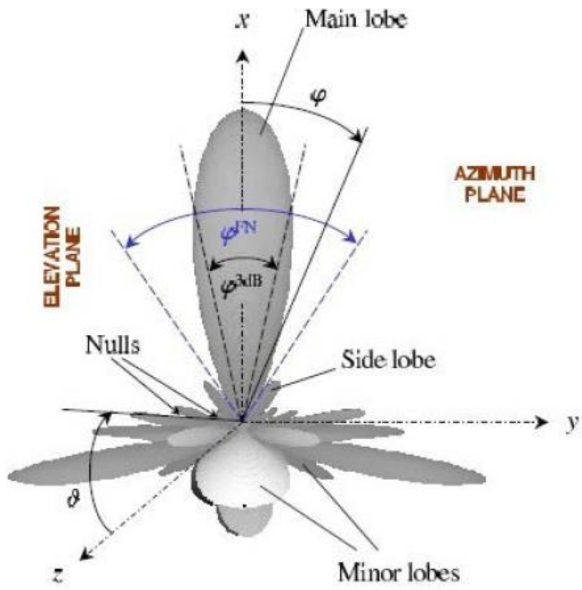

Fig-1: Example of a radiation pattern

But it encounter a serious drawback of strong self interference from its transmit antennas. This strong self interference can be annihilated considerably by the combined application of baseband analog cancellation and RF domain approach, however if multiple antenna beamforming is incorporated in the system the entire residual self interference can be excluded thus making full duplex systems interference free. Beamforming has been preferred over other techniques because of its property of high gain and interference mitigation. For future wireless communication systems design and implementation of smart antennas also referred to as adaptive antenna arrays gained much attention. These smart antennas when employed can enhance the capacity as well as range of the system utilizing adaptive beamformers which produce nulls towards interferes and direct the main beam towards the desired user[1]. This considerably increases the signal interference ratio. In contemporary wireless networks an improvement of antenna gain and interference suppression is mainly achieved through beamforming techniques. Traditional beamforming primarily used for analog devices required high expenditure on the hardware, however digital beamforming can be implemented through software thus eliminating the cost required for hardware setup. Beam patterns in case of digital beamformers are controlled using different algorithms such as MI (Matrix Inversion) for fixed beamforming and LMS (Least Mean Squares) , RLS (Recursive Least Squares) algorithms for adaptive beamforming. Digital beamforming can be categorized into two types on the basis of arrival angle at the reception. When the angle of arrival does not change with time array weights need not to be changed to drive the array elements for obtaining beam pattern .this is referred to as fixed beam forming .However when the angle of arrival changes with time the weights of array need to be changed dynamically to obtain various beam patterns as per real time .This is referred to as adaptive beamforming.

1.1 RELATED WORK.

Adnan Anwar et.al [1] in 2017 worked on the design and implementation of smart antennas using different beamforming techniques .Different algorithms were used according to the type of beamforming technique implemented and the performance comparison was made on the basis of nulls location, gain and Half Power Beam Width(HPBW). After simulation it was concluded that the gain of MI algorithms decreased drastically when the interferers were brought closer to main user. However LMS algorithm also faced the same trend for gain but it proved a bit efficient in terms of HPBW. In case of RLS algorithms the gain also degraded as the distance between SNOI(Signal Not Of Interest) and SOI(Signal Of Interest) were brought close to each other but HPBW remained fairly constant thus giving superior performance comparatively .MI algorithm was incorporated for fixed beamforming while as LMS and RLS were implemented for adaptive beamforming

Duckdong Hwang et.al [2] in October 2017 proposed in his paper about the design of a powerful tool for enhancing throughput and spectral efficiency using full duplex systems which can support a massive number of communication devices. However full duplex systems experience strong self interference. In this paper he devised a technique of suppressing this self interference by introducing the joint approaches of RF domain and baseband analog suppression to minimize interference effects up to larger extent. However the implementation of beamforming techniques suppressed entire residual interference present in full duplex systems thus making them almost interference free. In this paper he also formulated a technique of harvesting energy from self interference for charging the batteries at the receiver end instead of suppressing it through the process of self energy recycling.

M.shoriful Islam et.al [3] in 2016 proposed some beamforming techniques for the upcoming 5th generation of cellular communications. In this paper he compared performance analysis of different beamforming techniques like conventional adaptive and hybrid beamforming to realize the most efficient beamforming technique .He used different neural network models to realize adaptive beamforming. Firstly hop field model was used to analyze MMSE beamforming ,secondly he used feed forward network to find out input output relationship .From simulation and results he proved that the hybrid beamforming is most efficient and cost effective over digital and analog beamforming

Rothna et.al [4] in 2015 proposed two receive beam forming techniques to compensate the Carrier Frequency Offset [CFO] in the receivers .In this paper a performance comparison of different beam forming techniques in presence of CFOs was analyzed. Conventional beam forming when implemented does not yield CFO compensation, however when joint receive beamforming and spatial selectivity receive beamforming was implemented and was analyzed that spatial selectivity receive beamforming was more robust in presence of CFO errors compared todegraded performance of joint receive beamforming techniques.

2. BEAMFORMING TECHNIQUES

The various beamforming techniques that prove very much efficient in their implementation to upcoming wireless communications interms of beam power, angle of arrival, spatial multiplexing and interference mitigation are discussed as follows:

2.1 Analog Beamforming

In conventional cellular systems like Third Generation Partnership Project (3GPP) Long Term Evolution (LTE), precoding and combining are performed in baseband using DSP[6].This digital precoding allows better control over the entries of the precoding matrices,which in turn facilitates the implementation of sophisticated single-user, multi-user, and multicell precoding algorithms.Digital domain operation allows precoding and combining to be performed in conjunction with equalization, for instance in frequency domain with FDMA. The hardware constraints produced imply that digital baseband solutions are by and large infeasible in the close term for mmWave. Analog beamforming employing a network of phase shifters is a prompt solution to overcome the impediment on the number of complete RF chains.

The weights of the phase shifters are designed to shape and steer the transmit and receive beams along the dominant propagation directions.The capability of Analog beamforming is restricted by the accessibility of just quantized phase shifters and the limitations on the amplitudes of the phase shifters. These limitations make it difficult to shape multiple beams, finely tune the sidelobes, or steer nulls. Besides, analog beamforming/joining calculations are restricted to single-stream transmission; their augmentation to multi-stream or multi-client cases are not clear.

2.2 Hybrid Analog/Digital

Precoding And Combining

Digital precoding and joining take into account advanced transmission methodologies, yet with high complex nature and power utilization in mmWave frameworks[6]. Analog beamforming is generally simple,but only support single-stream transmission.

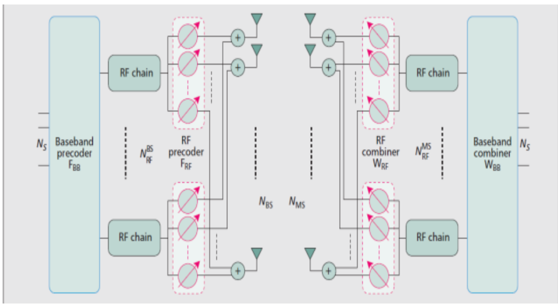

Fig-2: Hybrid analog/digital precoding and combining architecture.

Precoder processing in case of hybrid precoding[6] is divided among analog and digital domains as shown in the figure-2. Here the BS has N_{BS} antennas and N_{RF}^{BS} RF chains, and the mobile station has N_{MS} antennas and N_{RF}^{MS} RF chains such that $N^{BS} > N_{RF}^{BS}$ and $N^{MS} > N_{RF}^{MS}$. The precoding processing is divided between the analog and digital baseband precoding matrices $\mathbf{F}_{RF}$, $\mathbf{F}_{BB}$, and the combining at the mobile user is done using the analog and baseband combining matrices $\mathbf{W}_{RF}$, $\mathbf{W}_{BB}$. If $\mathbf{H}$ denotes the channel matrix, $\mathbf{s}$ represents the transmitted signal vector, and $\mathbf{n}$ represents the received noise vector, the received signal after combining is written as

$$\mathbf{y} = \mathbf{W}_{BB}^* \mathbf{W}_{RF}^* \mathbf{H}\mathbf{F}_{RF}\mathrm{BB}\mathbf{s} + \mathbf{W}_{BB}^* \mathbf{W}_{RF}^* \mathbf{n}. \quad (1)$$

The difference between the received signal in Eq. 1 and the typical MIMO signal model is the product of precoding and combining matrices, each implemented in a different domain and with different structural constraints.

2.3 Angle Of Arrival Estimation

Direction finding with linear arrays is limited to either the 0 or Ø directions.A planar array is needed to find direction in azimuth and elevation. Circular arrays are also commonly employed for direction finding.

For steering the beam to particular direction, the estimation of the angle of arrival plays a very vital role.

This is done by digital signal processing techniques, a few techniques are mentioned below :

1. Periodogram
2. Capon's Minimum Variance
3. MUSIC Algorithm
4. Pisarenko Harmonic Decomposition
5. Maxium entropy method
6. ESPIRIT - Estimation of Signal Parameters via .Rotational /invariance Techniques.

2.3.1.Periodogram

One way to determine the signals present in the vicinity of an array is to scan the beam over the region of interest and plot the output power as a function of angle. A graph representing output power against angle is known as a periodogram. Resolving closely spaced signals is limited by the array beamwidth[9].

2.3.2 Capon's Minimum Variance

In periodogram to detect signal locations main beam of an array is used. Since the main beam is wide, especially for small arrays, the ability to separate multiple signals or accurately locate a signal is not very good. Using nulls to locate signals is much more desirable, because the nulls have a narrow angular extent. Capon's method of estimating angle of arrival is the maximum likelihood estimate of the power coming from a direction of interest while all the other sources are considered interference[8]. Thus, the goal is to minimize the output power while forcing the desired signal to remain constant.

2.3.3.MUSIC Algorithm

MUSIC is an acronym for Multiple Signal Classification. MUSIC assumes the noise is uncorrelated and the signals are either uncorrelated or mildly correlated[10]. When the array calibration is perfect and the signals uncorrelated, then the MUSIC algorithm can accurately estimate the number of signals, the angle of arrivals, and the signal strengths.

The MUSIC algorithm is not very robust, so many improvements have been proposed. One popular modification, called root-MUSIC, accurately locates the direction of arrival by finding the roots of the array polynomial.

2.3.4.Maximum Entropy Method

The maximum entropy method (MEM) is also called the all-poles model or the autoregressive model[13]. MEM is based on a rational function model of the spectrum having all poles and no zeros. Hence, it can accurately reproduce sharp resonances in the spectrum.

2.3.5.Pisarenko Harmonic Decomposition

The smallest eigenvector (λ_N) minimises the MSE of the array output with the constraint that the norm of the weight vector equals one.

2.3.6.ESPRIT

ESPRIT is an acronym for Estimation of Signal Parameters via Rotational Invariance Techniques[16]. It is based upon breaking an N-element uniform linear array into two overlapping sub arrays with N-l elements. One sub array starts at the left end of the array, and the other starts at the right end of the array. The N - 2 shared elements in the middle are called matched pairs. ESPRIT makes use of the phase displacement between the two sub arrays to calculate the angle of arrivals for the signals.

This paper gives the detail about the different parameters that involved in the antenna array and the methods of finding them. The direction finding algorithms can assist in better finding the signal arrival direction while the amplitude tapering aids in maintaining a specific amount of sidelobe levels. On the other side, the number of antenna array elements helps in increasing the directivity.

3. CONCLUSION

Precoding and receiver design will be an important component of future cellular systems, and the next generation of wireless local area network standards. We present two precoding/combining strategies that take the different hardware constraints, different antenna scales, and different channel characteristics into consideration, making them suitable for operation in future wireless systems.Also from the above discussion it can be said that hybrid beamforming is the most efficient and reliable technology over analog and digital types because in case of digital beamforming more base band chains both in transmitter and reciever is the requirement which makes it costly compared to analog beamformers, however analog beamfomers require less base band chains in the receiver chain makindg it cost effective .Hybrid beamforming provides high data rate with less bit error rate which can be efficient for the implementation to future wireless technologies.

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