Comparative Study of different beamforming techniques for 5G: A Review

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***Abstract*- Due to beam forming, there will be increase in energy of signal to intended user and decreases in interference which is the prime requirements of mm wave communications required for high data rates and large capacity applications. Different beamforming techniques such as analog, digital, hybrid beam forming along with their associated methods have been studied and compared in this paper for searching optimum architecture in terms of energy efficiency. Antenna parameters like gain, half power beamwidth, scattering parameters are calculated at different frequencies by various authors using tools like ADS, HFSS, MATLAB, CST Microwave studio have been studied. While doing this comparison, both hardware as well as software (algorithms) aspects of the techniques have been considered.**

***Keywords*- beamforming, antenna, analog beamforming, digital beamforming, hybrid beamforming**

I INTRODUCTION

For transmission or reception of directional signal, beam forming is utilized in sensor arrays in which some angle experiences interference either constructive or destructive. Beam former monitor the amplitude and phase of signal at every transmitter for changing the directivity of an array. In beam forming, multiple antennas are used to control the direction of wave with the help of amplitude and phase of signals in an array. While doing this, space between the same signal sent from different antennas is kept as half of the wavelength. Depending upon the position of receiver, alignment of signal forms the constructive or destructive interference. Creation of directional beam using antenna array is shown in following figure [1].

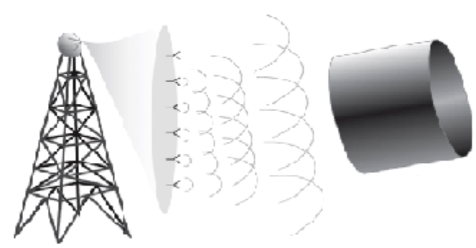

Fig. 1. Directional beam formation using antenna array

In wireless networks, for enabling a higher capacity and reducing co-channel interference smart antenna is the most dominant technology in which antenna can focus their beam pattern towards signal of interest (SOI) and mitigate the signal not of interest (SNOI). Smart antenna system divided into two types depending on beam forming technique, first one is switched (conventional or fixed) beam system and second one is adaptive (phase array) array system [2]. First antenna system can be easily constructed by using beam forming networks, number of radiating elements and RF switches [3]. Second system requires advanced signal processing and different intelligent algorithms. Analog beam forming network can be constructed using different techniques such as Butler matrix, Blas matrix, Nolen matrix and Rotmans Lens are studied in this paper. Digital beam forming can be classified based on angle of arrival from transmitter as fixed and adaptive beam forming. Algorithms for these techniques have been presented by different authors. Huge demand requirement of wireless communication system mainly depends upon spectral efficiency and bandwidth. Currently frequency range for wireless technology is from 0.3

GHz to 3 GHz frequency band [4]. System bandwidth can be explored as physical layer technology has already touched the Shannon capacity [5]. Therefore 5G wireless networks relies on exploration of high frequency mmWave frequency band ranging from 3 GHz to 300 GHz. Multiple Input Multiple Output (MIMO) technology along with multiple antennas at Tx and Rx is considered as promising method to enhances system efficiency [6]. To address these issues, researchers come up with hybrid beam forming (analog plus digital beam forming) techniques.

This paper is presented in the following way: In section II, literature review of different research paper has been carried out, section III consists of comparative discussion of various beam forming techniques such as analog, digital and hybrid beam forming and finally conclusion is mentioned in section IV based on some observations of different authors.

II LITERATURE REVIEW

The feeding network plays a vital role in beam forming antenna array which allocate the required magnitude and phase delay of signal to every antenna elements. There are mainly three topologies for implementing feeding network as series feeding, parallel feeding and matrix feeding. Out of which, matrix feeding is multiple input multiple output network which is suitable for mmWave communications[7]. 4x4 Butler matrix [8] is used as beam forming network which produces 4 narrow steerable beams when designed antenna array operated at 2.35 GHz and results are simulated on ADS and CST Microwave studio. Beamwidth and gain are calculated for 4 different ports each having bandwidth more than 100 MHz. This butler matrix is passive feed network which is formed by using phase shifters, couplers and crossovers. Phase difference between ports at output of Butler feed observed as constant. In [9], Hassanien et.al., introduced Rotman Lens beam forming technique which designed steerable system at frequency ranges from 25 GHz-30 GHz and covers scanning angle from -45^0 to 45^o. This system provides good performance in terms of scattering parameters and beam steering characteristics. Rotman Lens provides wide scanning angle, low cost and easy to implement [10]. It has true time delay characteristics means it steers the beam which is independent on operating frequency and have high bandwidth [11]. 3x3 Nolen matrix [7] consists of coupling ratios and phase shifters which provide arbitrary phase difference. Blas matrix [12] can be designed using couplers, phase shifters and load terminations but has more power loss that becomes challenging issue in Blas matrix. Nolen matrix [13] was developed by cutting partially Blas matrix along diagonal line and replacing diagonal coupler by transmission line which solved the problem of power loss in Blas matrix and hence reduces the number of components.

Phase shifters steer main beam to SOI in case of traditional antenna arrays. But in modern antenna array, beam forming is done by smart antennas known as digital beam formed array which are based on algorithmic logic. According to this logic, beam is allowed to steer towards SOI and null towards SNOI. When angle of arrival from transmitter do not change with time, optimum array weights need not to be adjusted is called as fixed digital beam forming whereas optimum array weights need to adjust when angle of arrival changes with time is known as adaptive digital beam forming. This different digital beam forming algorithm performance compared on eight element linear patch array antenna operating on 2.4 GHz frequency for LTE applications and results are simulated on MATLAB and HFSS software [14]. Matrix Inversion algorithm applied to fixed beam forming works on linear algebra method [15] for computing complex weights. Least Mean Square (LMS) method is the simplest algorithm applied to compute adaptive weights in real time which works on gradient descent method to calculate weights. This algorithm is not suitable for highly noisy environment [16]. To overcome this drawback, weight in LMS has to compute recursively using Recursive LMS algorithm.

The number of transmitted data stream lower bounds the numbers of RF chains whereas antenna elements govern beam forming gain and diversity order that forms the motivation for hybrid beam forming [17]. As compared to conventional digital beam forming, hybrid beam forming requires less hardware and consumes less power. For lowering energy consumption in mmWave systems, hybrid (analog and digital) structures have been proposed [18]. To obtain benefits of MIMI and for getting high beam forming gain to overcome high propagation loss in mmWave bands required for 5G cellular communications, hybrid beam forming structures are proposed [19].Mainly there are two types of hybrid beam forming architectures as fully connected (one to one connection between RF chain and all antennas) and partially connected (one RF chain and set of antenna elements connection) which are explained and compared by Irfan Ahmad et. al.,in [20].

III REVIEW OF SURVEY PAPERS ON BEAMFORMING IN 5G

A] Analog Beam Forming

The process of beam forming in which amplitude or phase variation is applied to analog signal at transmitter end and signal received from different antennas are summed up before applied to ADC in receiver end is called as analog beam forming. Analog beam former consists of transmitter modules which are used to control amplitude and phase of transmitted signal of each antenna element. This type of beam forming technique can be achieved by using Butler matrix, Nolen matrix or Blas matrix feeding techniques which has been explained by different authors compared in following table based on certain parameters:

TABLE I: COMPARISON OF BUTLER MATRIX, BLAS MATRIX and NOLEN MATRIX

Parameters	Butler Matrix	Blas Matrix	Nolen Matrix
Construction	Hybrid couplers, crossover, phase shifter	Couplers, phase shifters, load terminations	Couplers, phase shifters
Degree of freedom	Less	Moderate	High
Efficiency	High	Less	Moderate
Power loss	Low	High	Moderate
Design	Simple	Moderate	Complex

B] Digital Beam Forming

Before DAC conversion at transmitter end, amplitude or phase variation is applied to digital signal is known as digital beam forming. This beam forming implies weighting these digital signals such that when added together forms desired beam. In order to achieve digital beam forming, different algorithms like Matrix Inversion (MI) algorithm, Least Mean Square (LMS) algorithm and Recursive Least Mean Square (RLMS) algorithm have been studied and compared in following table.

TABLE II: COMPARISON OF MI, LMS and RLMS ALGORITHMS

Parameters	Matrix Inversion	Least Mean Square	Recursive Least Mean Square
Logic	Linear Algebra	Gradient descent method	Gradient descent method in recursive fashion
Methodology	Matrix	Eigen values	Eigen values
Memory	Not required	Required	Required
Complexity	High	Low	Moderate
Application	Fixed beam forming	Adaptive beam forming	Adaptive beam forming in noisy environment
Quality of Service	Poor due to more interference	Moderate	Good

C] Hybrid Beam forming

Analog beam forming suffers from inter user interface and less accuracy problem whereas digital beam forming is complex and costly. Considering these disadvantages and advantages like simplicity of analog and high degree of freedom of digital beam forming techniques, researchers came up with solution of hybrid beam forming that is combination of analog and digital beam forming which can fulfill the growing energy efficiency and spectrum efficiency requirement of mmWave communication necessary for 5G communications.

IV CONCLUSION

After comparative study of different feeding techniques for analog beam forming, it has been observed that Butler Matrix is the potential technique to implement corresponding beam forming as it provides high directivity compared to Blas and Nolen matrix. Complex weights can be calculated using Matrix Inversion Algorithm in case of digital fixed beam forming whereas Recursive Least Mean Square Algorithm provides good convergence and better result for digital adaptive beam forming over noisy environment. Hybrid beam forming enables mmWave massive MIMO communications that opens the door for 5G communications.

REFERENCES

[1]https://www.rcrwireless.com/20180912/5g/5g-nr-massive-mimo-and-beamforming-what-does-it-mean-and-how-can-i-measure-it-in-the-field

[2] Milind Fernandes, Aniket Bhandare, Chetan Dessai, dan Hassanali Virani, “A Wideband Switched *Beam* Patch Antenna Array for LTE and Wi-Fi”, Annual IEEE India Conference (INDICON), 2013.

[3] Y. J. Chang and R. B. Hwang “Switched beam System for low-tier wireless communication systems,” in Proceedings of the 2001 Asia Pacific Microwave Conference, Taipei, Taiwan, December 2001, pp. 946-949.

[4] J. G. Andrews et al., “What will 5G be?” IEEE J. Sel. Areas Commun., vol. 32, no. 6, pp. 1065–1082, Jun. 2014.

[5] B. Bangerter, S. Talwar, R. Arefi, and K. Stewart, “Networks and devices for the 5G era,” IEEE Commun. Mag., vol. 52, no. 2, pp. 90–96, Feb. 2014.

[6] A. F. Molisch et al., “Hybrid beamforming for massive MIMO: A survey,” IEEE Commun. Mag., vol. 55, no. 9, pp. 134–141, Sep. 2017.

[7] H. Ren et al., “A Novel 2-D 3 × 3 Nolen Matrix for 2-D Beamforming Applications,” IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 67, NO. 11, NOVEMBER 2019.

[8] Fitri, Nurul, Basari, Rahardjo, “Design of Butler Matrix Integrated with Antenna Array for Beam Forming ,” IEICE 2015.

[9] M A Hassanien, et. al., “Wideband Rotman Lens Beamforming Technique for 5G Wireless Applications,” IEEE 2019.

[10] W. Rotman and R. Turner, “Wide-angle microwave lens for line source applications,” IEEE Trans. Antennas Propag., vol. 11, no.6, 1963.

[11] A. Lambrecht, S. Member, S. Beer, T. Zwick, and S. Member, “True-Time-Delay Beamforming With a Rotman-Lens for Ultrawideband Antenna Systems,” vol. 58, no. 10, pp. 3189– 3195, 2010.

[12] J. Blass, “Multidirectional antenna—A new approach to stacked beams,” in Proc. IRE Int. Conf. Rec., vol. 8, 1960, pp. 48–50.

[13] J. Nolen, Synthesis of Multiple Beam Networks for Arbitrary Illuminations. South Bend, IN, USA: Bendix Corporation, 1965.

[14] Awan et. al., “Performance Comparisons of Fixed and Adaptive Beamforming Techniques for 4G Smart Antennas,” International Conference on Communication, Computing and Digital Systems, 2017.

[15] Alberto Moreira, “Digital Beamforming: A Paradigm Shift for Space borne SAR” 14th International Radar Symposium (IRS), 19-21 June 2013.

[16] L. Alonso, S. Ver Hoeye, M. Fernandez, C. V ´ azquez, R. Camblor, G. Hotopan, A. Hadarig and F. Las-Heras, “Millimetre Wave Textile Integrated Waveguide Beamforming Antenna for Radar Applications” Millimeter Waves (GSMM), Global Symposium, 25-27 May 2015.

[17] A. F. Molisch et al., “Hybrid beamforming for massive MIMO—A survey,” arXiv Preprint arXiv1609.05078, pp. 1–14, Sep. 2016.

[18] W. Roh et al., “Millimeter-wave beamforming as an enabling technology for 5G cellular communications: Theoretical feasibility and prototype results,” IEEE Commun. Mag., vol. 52, no. 2, pp. 106–113, Feb. 2014.

[19] W. Roh et al., “Millimeter-wave beamforming as an enabling technology for 5G cellular communications: Theoretical feasibility and prototype results,” IEEE Commun. Mag., vol. 52, no. 2, pp. 106–113, Feb. 2014.

[20] Irfan Ahmed et. al., “A Survey on Hybrid Beamforming Techniques in 5G: Architecture and System Model Perspectives,” IEEE COMMUNICATIONS SURVEYS & TUTORIALS, VOL. 20, NO. 4, FOURTH QUARTER 2018.