HYBRID BEAMFORMING TECHNIQUE FOR MILLIMETER WAVE MIMO SYSTEM

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ABSTRACT

Wireless telecommunications have continued to attract attention for more than a decade. One of the current challenges is to ensure an increase in transmission rates while guaranteeing a certain quality of service. For this, several techniques are envisaged. The use of MIMO systems is one of the techniques. The rise in frequency to the millimeter wave spectrum is also available to meet a need for broadband. This paper is based on the combination of these two techniques, focusing on the technique of antenna beamforming.

Keywords: *Beamforming (BF), MIMO, mm Wave.*

1. INTRODUCTION

Currently there is a switch to a digital world where via the internet access to information is very simple and very fast. However, scanned documents can be copied, edited and then re-posted on the internet without worrying about copyrights.
Even though some organizations are fighting piracy this has not solved the problem of copyrights, so we opted for tattooing. It consists of inserting a mark called "signature" that only authorized persons can detect thus proving the integrity of any document.
The increasing demands to enhance the data rate and capacity raise needs for new generation wireless communication networks [1].
Several frequency bands are available for high data rate applications at millimeter wave (mm Wave) bands [2], [3]. A very high frequency, wider bandwidth and even the high Bit Rate is possible in small cell. One simple approach is to use beamforming (BF) by applying MIMO technology at mm Wave bands. It can be used to transmit signals which use the BF weight candidates [4].
The combination of analog fixed BF and the digital precoding is known as hybrid BF. It can be very much effective to reduce the cost of the MIMO transceiver [1].

2. RELATED STUDY

2.1 Multiple Input Multiple Output (MIMO)

MIMO wireless communication refers to the cellular station with a multiple number of antennas at the transmitter and receiver, which has been shown to improve the performance in spectral and energy efficiency. It is assumed that the passing information is complex numbers: all data are complex random variables. The channel models how the transmitted signal is modified before it's received. We therefore search the capacity of the transmission's channel which is performed under a constraint on the average power of the transmitted signal.

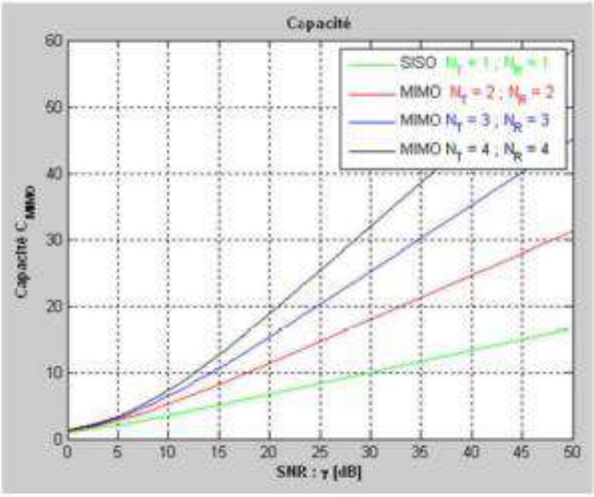

Fig - 1: Capacity of MIMO channel according to the Signal-To-Noise Ratio (SNR)

The ultimate actualization and work out of the 5G radio access network with a super high data rate and high capacity depend on the need of small cells utilizing for both higher frequency bands and MIMO technology. The use of MIMO technology improves the reception and allows a better range and diversity. It's also gives millimeter-wave applications a significant increase in spectral efficiency.

2.2 Millimeter Wave (mm Wave)

The millimeter waves belong to the last zone of the radio spectrum before the terahertz, which refers to the radio spectral range extending from 30 to 300 GHz, a wavelength of between 1 mm and 10 mm. This means they are larger than infrared waves or x-rays, for example, but smaller than radio waves or microwaves. The millimeter-wave region of the electromagnetic spectrum corresponds to the radio band frequency range of 30–300 GHz and is also called the extremely high frequency (EHF) range. The high frequencies of millimeter waves, as well as their propagation characteristics (i.e., the ways they change or interact with the atmosphere as they travel), make them useful for a variety of applications, including the transmission of large amounts of data, cellular communications, and radar [5].
The mm-wave band in the 30-300GHz frequency range is being taken into account for proceeding 5G to achieve 1000 times more data traffic [5]. Due to the advancement of semiconductor technology helps to open scopes for very low cost and low power consumption of mm-wave components [6]. As a result, mm-wave systems offer a huge bandwidth to implement the 5G communication. However, the use of mm-wave technology is limited because of harsh propagation conditions. So high path loss happens that reduces receive volume signal because receive antenna size is small to support short wavelength and high thermal noise decreases SNR that brings about from wider bandwidth.

2.3 Beamforming

The MIMO antenna array is used to orient and control the radio wave beam (amplitude beam and phase beam). Constructive / destructive lobes can be created and transmission between the transmitter and the target optimized. The beamforming technique makes it both possible to extend a radio coverage (of a base station for example) and to limit the interference between users and the surrounding electromagnetic pollution. Beamforming is a method used to generate the radiation pattern of an array antenna.
In the case of millimeter-wave wireless systems, the beamforming function not only considers the antenna radiation pattern but focuses on maximizing the SNR received under dynamic conditions. Beamforming is employed at both the transmitting and receiving terminals in order to introduce spatial selectivity, this system provides the antenna arrays to monitor their beams and transmit data into a certain direction which is also known as spatial filtering.

- Mathematic modeling

In this section, it is assumed that the millimeter-wave beamforming system model is bidirectional. An example is shown in Fig. 2. Two devices, DEV1 and DEV2 exchange information using mm wave wireless communication. At the same time, DEV1 and DEV2 can use the same physical antennas for transmission and reception.

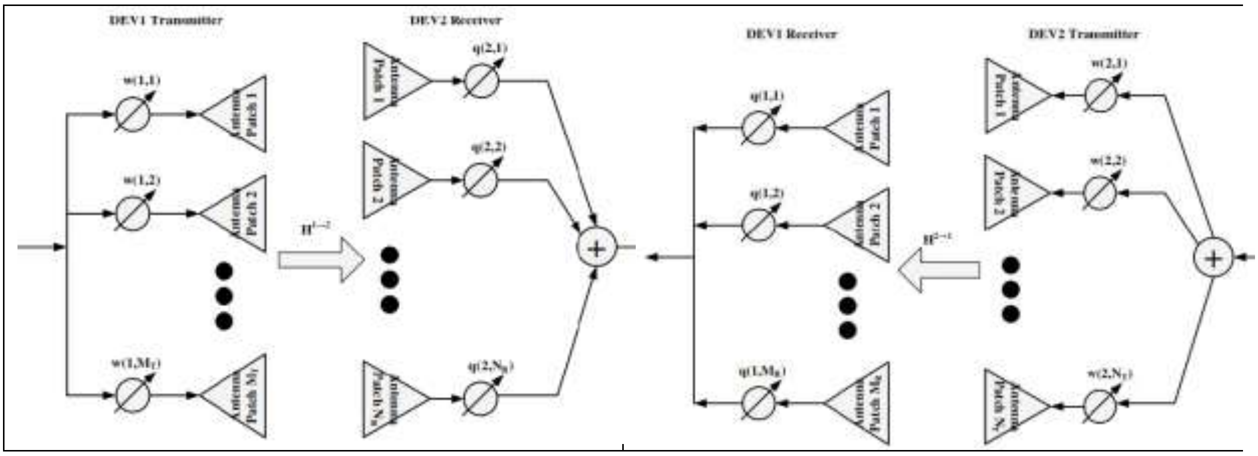

Fig - 2: Beamforming Technique. (a) transmitter, (b) receiver

Consider an Orthogonal Frequency Division Multiplexing (OFDM) symbol radiating from DEV1 to DEV2 that can be expressed as:

$$x(t) = \sum_{n=0}^{N-1} s_n \delta(t - nT_c) \quad (1)$$

T_c : Sampling period

$\{s_n\}_{n=0}^{N-1}$: complex data, $s_n \in \mathbb{C}$ which depends on the modulation plan.

N : number of subcarriers and

$$\delta(t) = \begin{cases} 1 \; if \; 0 \le t \le T_c \\ 0 \; elsewhere \end{cases}$$

- Expression of beamforming vector

At the transmitter of DEV1, each s_n is processed by the following beamforming vector:

$$W_1 = [W(1,1) \quad W(1,2) \quad \dots \quad W(1, M_T)]^T \quad (2)$$

Then transmitted in a MIMO channel with frequency domain channel status information, (CSI) $H^{1\to 2}(n) \in \mathbb{C}^{N_R \times M_T}$ to the i^{th} subcarrier for $0 \le n \le N$ which is expressed by:

$$H^{1\to 2}(n) = \begin{bmatrix} h_{1,1}^{1\to 2}(n) & h_{1,2}^{1\to 2}(n) & \cdots & h_{1,M_T}^{1\to 2}(n) \\ h_{2,1}^{1\to 2}(n) & h_{2,2}^{1\to 2}(n) & \dots & h_{2,M_T}^{1\to 2}(n) \\ \vdots & \vdots & & \vdots \\ h_{N_R,1}^{1\to 2}(n) & h_{N_R,2}^{1\to 2}(n) & \cdots & h_{N_R,M_T}^{1\to 2}(n) \end{bmatrix} \quad (3)$$

$h_{i,j}^{1\to 2}(n)$: transfer function of the channel from the j^{th} transmitting antenna until i^{th} receiving antenna of DEV2.

At the receiver, the received signal is processed by the combinatorial vector Q_2:

$$Q_2 = [q(2,1) \quad q(2,2) \quad \cdots \quad q(2, N_R)]^T \quad (4)$$

The equivalent channel between transmitter of DEV1 and receiver of DEV2 is a single input single output channel (SISO), with a frequency response to the n^{th} subcarrier $(0 \le n \le N)$ given by:

$$p_n = Q_2^H H^{1\to 2}(n) W_1 \text{ for } 0 \le n \le N-1 \quad (5)$$

The discrete signal received becomes:

$$y_n = p_n s_n + b_n \text{ for } 0 \le n \le N-1 \quad (6)$$

$\{s_n\}_{n=0}^{N-1}$: OFDM data symbol

$\{b_n\}_{n=0}^{N-1}$: additive Gaussian white noise vector with variance N_0

Then transmitted in a MIMO channel with frequency domain channel status information (CSI) $H^{2\to 1}(n) \in \mathbb{C}^{M_R \times N_T}$ to the n^{th} subcarrier for $0 \le n \le N$ which is expressed by:

$$H^{2\to1}(n) = \begin{bmatrix} h_{1,1}^{2\to1}(n) & h_{1,2}^{2\to1}(n) & \cdots & h_{1,N_T}^{2\to1}(n) \\ h_{2,1}^{2\to1}(n) & h_{2,2}^{2\to1}(n) & \cdots & h_{2,N_T}^{2\to1}(n) \\ \vdots & \vdots & \ddots & \vdots \\ h_{M_R,1}^{2\to1}(n) & h_{M_R,2}^{2\to1}(n) & \cdots & h_{M_R,N_T}^{2\to1}(n) \end{bmatrix} \quad (7)$$

$h_{i,j}^{2\to1}(n)$: Channel's transfer function from the j^{th} transmitting antenna of DEV2 to the i^{th} receiving antenna of DEV1.

At the receiver of DEV1, the received signal is processed by the combinatorial vector Q_1.

$$Q_1 = [q(1,1) \quad q(1,2) \quad \cdots \quad q(1,M_R)]^T \quad (8)$$

The equivalent channel between transmitter of DEV2 and receiver of DEV1 is a single input single output channel, with a frequency response to the subcarrier $(0 \leq n \leq N-1)$ given by:

$$I_n = Q_1^H H^{2\to1}(n) W_2 \text{ for } 0 \leq n \leq N-1 \quad (9)$$

- Expression of SNR

When the link from the transmitter of DEV1 to the receiver of DEV2 is considered, the SNR on the n^{th}subcarrier is expressed as follows:

$$SNR_n^{1\to2} = \frac{E_s|p_n|^2}{N_0} = \frac{E_s|Q_2^H H^{1\to2}(n) W_1|^2}{N_0} \quad (10)$$

Where E_s is the energy per symbol, while if the link from the DEV2 transmitter to the DEV1 receiver is considered, the SNR on the n^{th} subcarrier is expressed as follows:

$$SNR_n^{2\to1} = \frac{E_s|I_n|^2}{N_0} = \frac{E_s\left|Q_1^H H^{2\to1}(n) W_2\right|^2}{N_0} \quad (11)$$

- Beamforming algorithm

Algorithm 1: Beamforming

Step1, Acquisition: DEV1 will train DEV2 by repeating transmission of beacon signals using W_1 selected from a sufficient subset of the beam former codebook. After that DEV2 will acquire the channel state information (CSI) by using a sufficient subset of its combiner codebook.

Step 2, Estimation: DEV2 will estimate the optimal beam former vector W_1 and optimal combiner vectorQ_2, which is related to the coefficients of quantized phase shifters.

Step 3, Feedback: DEV2 should feedback the optimal beam former W_1 and possibly optimal combiner vector Q_2 to DEV1.

Step 4, Tracking: DEV1 tracks the beam former and the combiner vectors continuously by sending beacon signals using W_1 selected from a sufficient subset of the beam former codebook at a lower rate compared with the acquisition phase.

Step 5, Update: DEV2 should feedback the optimal beam former W_1 and possibly optimal combiner vector Q_2 to DEV1 at a lower rate compared with the acquisition phase.

We define an effective SNR (ESNR) as a match between instantaneous subcarriers at an equivalent SNR, which takes into account the forward error correction.

The ultimate goal of a beamforming algorithm is to select the optimal beamforming vector W_1 to DEV1 and W_2 to DEV2, as well as the combiners Q_1 to DEV1 and Q_2 to DEV2 that maximizes the ESNR.

2.4 Hybrid beamforming

The main objective of a hybrid beamforming design is an architecture that is properly partitioned between the RF and digital domains. The design also includes the sets of precoding weights and RF phase shifts needed to meet the design goal of improving virtual connections between the base station and the user equipment (UE) [7].

Hybrid beamforming designs are developed by combining multiple array elements into subarray modules. A T/R module is dedicated to a subarray within the larger array, and therefore fewer T/R modules are required in the system. The number of elements, and the positioning within each subarray, can be selected to ensure that system-level performance is met across a range of steering angles. This approach translates directly into less system hardware.

For a hybrid beamforming design, it is also important to include the full set of system components in the system model to ensure optimized link-level system performance. Understanding how design choices affect bit error rate (BER), spectral efficiency, and channel capacity before systems are fabricated is critical. It is also important to have the option to perform signal processing where it is the most effective. Having a model for each portion of the system makes system design easier. Ideas can be tried at the lowest cost point in the project life cycle [7].

3. SIMULATION AND RESULTS

In this simulation, hybrid beamforming has been observed. We use 4 subarrays of 8 patch antennas operating at 66GHz (i.e. 8x4=32 antennas). Digital beamforming is applied to the subarrays (azimuth steering). RF beamforming (phase shifters) is applied to the 8 antennas (elevation steering). The directions at which to perform beamforming is 30-degree azimuth and 60-degree elevation. The whole simulation has been done by using MATLAB simulation.

3.1 Steering URA (Uniform Replicated Arrays)

The subarray weights can only make sure that the URA steers towards the azimuth direction.From Fig. 3. , it can be observed that the beam power is maximum in 30-degree because the main lobe is directed in that particular direction.

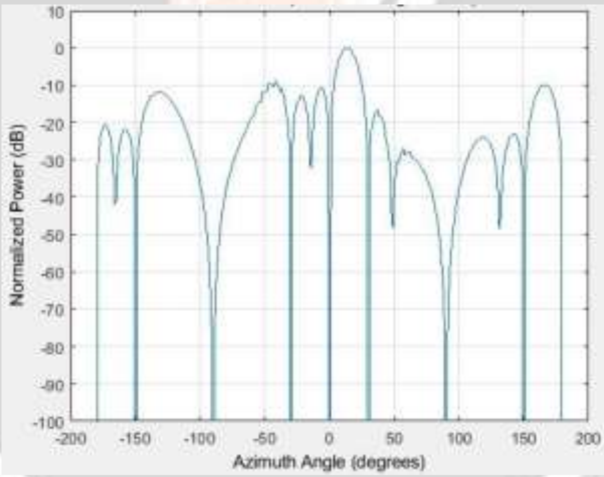

Fig - 3: Normalized Beam Power[dB] azimuth

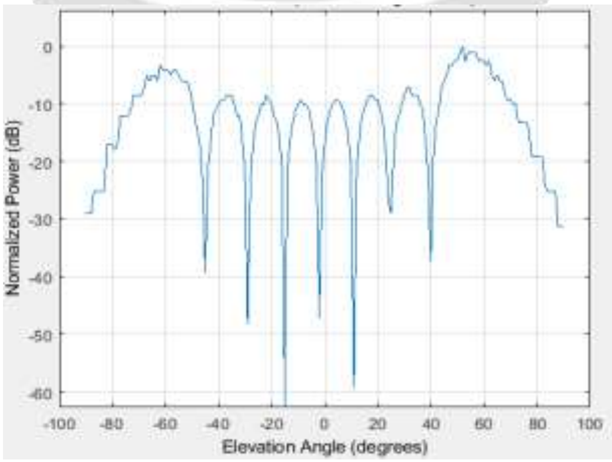

Fig - 4: Beam Power [dB] elevation

In case of Fig. 4. , each subarray can only influence the elevation steering angle. The angle is 60-degree and it is quite clear from the figure that the main lobe is directed in that particular direction and the side lobe are very small which are located within 0.1 amplitude and the value of main lobe is 1.

3.2 Verification: Steering a single subarray ULA (Uniform Linear Arrays)

After building an $N \times M$ rectangular URA array (no subarrays) and Computing weights it, we have these normalized beam power diagram.

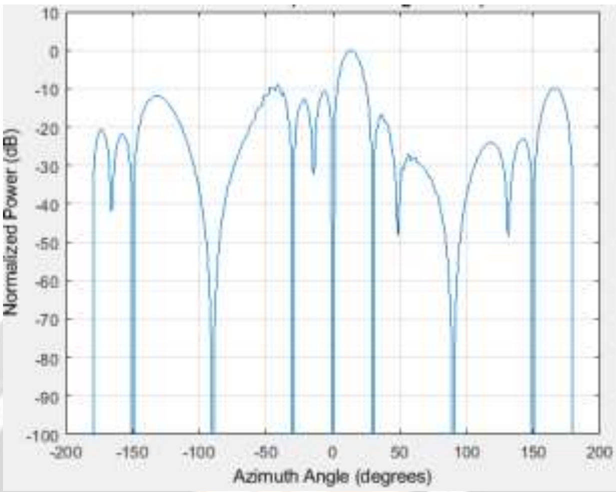

Fig - 5: Normalized Beam Power [dB] azimuth with single subarray ULA

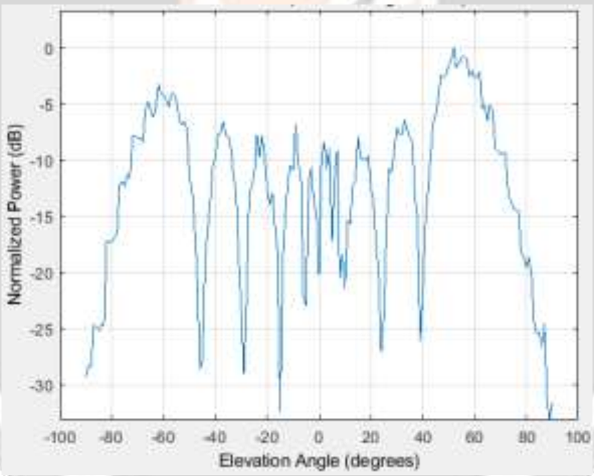

Fig - 6: Normalized Beam Power [dB] elevation with single subarray ULA

Digital and RF Beamforming technique has been observed and it is clear that the digital Beamforming provided far better spectrum compare to RF Beamforming.

4. CONCLUSION

From the simulation and the results, by combining Digital and RF beamforming, we have hybrid beamforming that is more reliable and effective. So, the hybrid Beamforming can be very much cost effective. Hybrid Beamforming can provide high data rate with very low BER which can be effective remarkably to implement 5G.

5. REFERENCES

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