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CODEBOOK DESIGN FOR MILLIMETER- WAVE MASSIVE MIMO SYSTEMS RELYING ON LAA

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Abstract:

This paper studies the fundamental relations between key design parameters of millimeter wave (mmWave) multiple input multiple output (MIMO) communication systems and subarray structures deployed at both the transmitter and the receiver with each radio frequency (RF) chain connected to only a specific subset of the antennas. The concept of effective degrees of freedom (EDoF) is introduced to measure the maximum spatial multiplexing gain available for the MIMO system. An analytical expression for the EDoF with respect to the parameters of antenna configuration and transmission distance is obtained for the line of sight (LoS) scenario. In addition, the upper and lower bounds of the EDoF are further obtained for some special cases. A fast beam training algorithm based on the codebook is developed to reduce the number of training for the designed mmWave system. Extensive simulation results indicate that the proposed scheme reduces the computational load of the exhaustive approach with only minimal loss in performance. Moreover, the proposed design is robust to the geometrical change and misplacement.

Keywords: Millimeter wave (mmWave), Antenna deployment, Beam training, Line of sight (LoS), Multiple input multiple output (MIMO).

1. INTRODUCTION

Motivated by the ever increasing growth in multimedia applications and the number of users, millimeter wave (mmWave) has been regarded as an essential technique for the next generation wireless communication network [1]. The multiple gigabit per second (Gbps) date rate requirements of future broadband systems can be satisfied by large swathes of unlicensed spectrums around the mmWave band [2]. Besides, the remarkable advancements in the mmWave hardware make it feasible to adopt mmWave band in many applications [3]. Spectral efficiencies can be further improved by employing multiple antennas, where multiple independent data streams are transmitted and received in parallel through spatial multiplexing without extra bandwidth or transmit power. The advantages of multiple input multiple output (MIMO) techniques rely heavily on the unique propagation characteristics of wireless channels. It is well known that mmWave channels are usually characterized with sparse scattering structures, which are unfavorable for MIMO systems [5, 6]. Most previous research on MIMO techniques are based on the dense scattering environment to enable spatial multiplexing [4]. While mmWave communications usually take place in the strong line of sight (LoS) circumstances where the channel responses are rank deficient, the spatial multiplexing gain can still be obtained by employing carefully designed antenna arrays thanks

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to the short wavelength [7]. Some efforts have been made on this topic, both for indoor scenarios [8, 9] and outdoor scenarios. Digital beamforming is traditionally designed based on channel state information (CSI) to improve communication quality at the advantages of digital processing techniques, such as interference cancellation and formation of multiple simultaneous beams. Analog beamforming is put forward to overcome the radio frequency (RF) hardware limitations where a network of analog phase shifters is employed to control the phase of the signal at each antenna. In this paper, we propose an efficient beam-training scheme for mmWave LoS MIMO communication systems with subarray structures at both the transmitter and the receiver. The subarray structure with directional antenna elements and phase shifters is designed to maximize effective degrees of freedom (EDoF) so that more multiplexing gain is available. An estimation for the separation between subarrays is also performed when the required EDoF are smaller than the number of RF chains.

2. RELATED WORK

The codebook design method from is employed in the proposed beam training scheme to apply for the situation where explicit CSI is unavailable. Furthermore, the proposed scheme focuses on the selection strategy of code words and is aimed at shortening training time as much as possible. In a word, the proposed beam training scheme includes several iterative training steps, where code words from the codebook are selected and trained at each step. Numerical results show that the proposed scheme has some advantages over the existing counterparts.

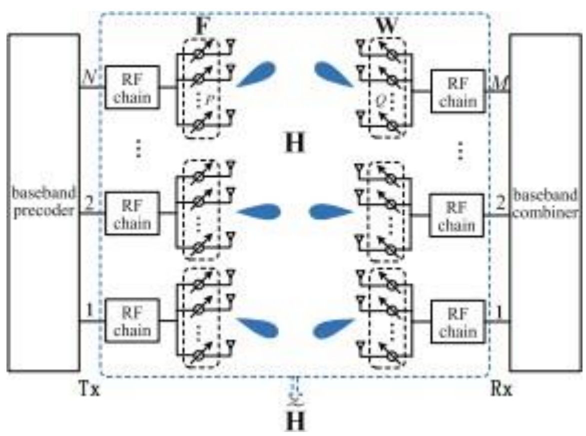

Fig.1. System

The rest of this paper is organized as follows. Section 2 introduces the system architecture and channel models, Section 3 provides the optimal design criterion of the normalized subarray separation product for maximizing EDoF in the subarray structure. Section 4 provides the proposed low complexity beam training scheme. Simulation results of EDoF and capacity performance are presented in Section 5, and conclusions are given in Section 6. Considering a point-to-point mmWave MIMO communication system in Fig. 1, where both the transmitter (Tx) and the receiver (Rx) adopt a subarray structure with some phase shifters to construct directional beams. In the subarray structure, each RF chain is connected to only a subset of the antennas, which is different from the fullyconnected structure where each RF chain is

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connected to all antennas. There are totally Nt transmit antennas and Nr receive antennas which are divided into N transmit subarrays and M receive subarrays equally. Without loss of generality, we assume that M N, and each transmit subarray is equipped with P antennas and each receive subarray is equipped with Q antennas. The antenna elements in each subarray are driven by the same RF chain but connected to a single phase shifter.

3. PROPOSED SYSTEM

Thus, the effect of path loss differences among antennas can be ignored, and only the phase difference caused by separate propagation paths is considered. The distance between the last element of one subarray and the first element of the next one subarray is Dt (Dr) for the transmitter (receiver). z0 is the position shift of the receiver along the z-axis. θ and φ are the angles of the local spherical coordinate system at the receiver. Assume that the distance R between the transmitter and the receiver is much larger than dt, dr. Due to the large size of the antenna array and the large propagation loss, a large number of training data and feedback information is essential to realize the exact phase shifts and amplitude adjustments for the phase shift networks.

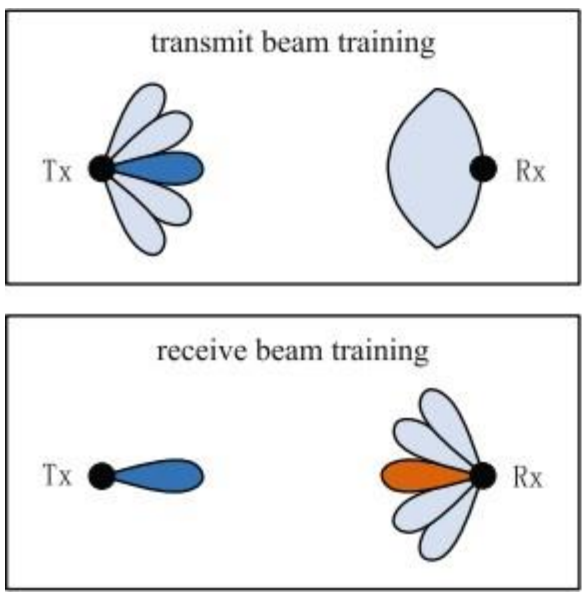

Fig.2.Transmitting System

However, the heavy training overhead is incompatible with the low power consumption and low complexity requirements for mmWave communications Therefore, a codebook-based solution with only quantized phase shift but without any amplitude adjustment of the elements of the RF precoder is adopted to simplify this procedure and reach a tradeoff between the complexity and the performance. In this paper, the beamformimg vectors and the combining vectors are selected from predefined codebooks. , the gap between the greatest and smallest eigenvalue will becomes lager. As a result, those SISO subchannels with small power gains make little contributions to the channel capacity and become non effective. In

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practice, each data stream can be assigned for more than one RF chains at the advantage of diversity techniques. So the required EDoF is usually smaller than the number of RF chains and Eq.

4. ANALYSIS

For description convenience, a small size transmit code are selected as referenced codewords for different steps. It can be seen from the picture that more than one path exits between the first chosen codeword and the final optimized codeword. Assuming that the fourth codeword is the desired one, there are three paths achieving the destination code word. If errors occur in the first or second step, they can be revised by latter steps. So, the proposed algorithm can tolerate errors. In this section, numerical results are presented to evaluate the effectiveness of the proposed design criterion with the optimal channel quality and the beam training scheme with low complexity In contrast, the complexity of the proposed algorithm is approximately logarithmic with the codebook size.

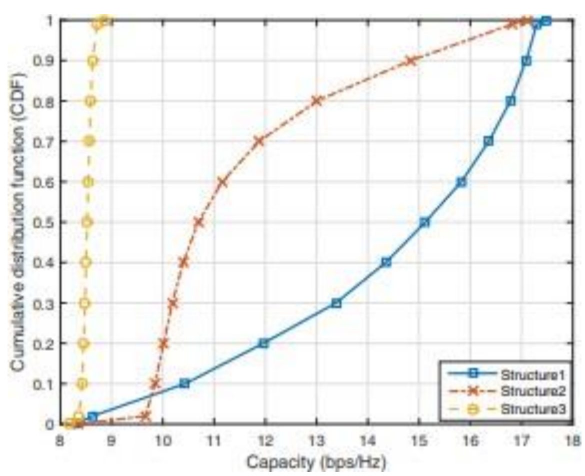

Fig.3.Analysis

Therefore, the complexity of the proposed algorithm is close to that of Algorithm In the proposed scheme, both the transmitter and the receiver are required to allocate a certain area of memory space to keep codewords and record the results of multiple feedback. In addition, the amount of feedback is subarray separation product. When Kf = 0 dB, the EDoF, and thus the system capacity, is almost independent of the normalized subarray separation product. Besides, the existence of the NLoS component gives an increase in the EDoF at those points deviating from the optimal criterion. An intuitive explanation is that the NLoS component causes the multipath effect which can increase the rank of the channel response matrix. The proposed algorithm is started from training the codeword with index l0 = 1. The receiver with the least position shift z0 converges to the maximum capacity quickly as the original referenced codeword is close to the desired one. The initial values of these curves decrease as the receiver position shift increases. However, all the curves converge to the same capacity when the sixth iterative training step is completed. Besides, the convergence rate of the proposed algorithm depends on the channel condition, the number of antennas in each subarray, the codebook size, and the choice of the original referenced codeword.

CONCLUSION

The subarray structure was designed to realize high EDoF MIMO transmission for wireless channels with a strong LoS component. The criterion showed that the optimal subarray separation product is proportional to the transmission distance multiplied by the wavelength and inversely proportional to the number of RF chains multiplied by the cosine of the spherical angle θ at the receiver. The iterative training scheme had the complexity logarithmic with the codebook size and outperformed some existing algorithms. Although LoS channels are in general rank deficient, the communication system with the proposed scheme can afford both array gains and spatial multiplexing gains through carefully designed antenna subarray spacing and appropriate beam training at both the transmitter and the receiver. In addition, the system designed.

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