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Estimation of Channel in Millimeter Wave Cellular Radio Systems

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***Abstract:** Mm Wave-communications systems are used in 5th Generation mobile networks. Systems that combine mmWaves, massive MIMO create a spectrum with greater spectral and spatial efficiency. These antennas are so small enough to support antenna arrays not only at the base stations, but also in the handsets. However, technology challenges are greater at mmWave frequencies, and bringing mmWaves to the marketplace will require understanding channel and network models.*

Millimeter wave cellular systems provide very high speed data Rates in the order of gigabit-per-second due to the availability of the large bandwidth that frequencies. These systems equipped with large antenna arrays with directional beam forming both at the transmitter and receiver. Because of the large number of antennas analog beam forming requires mmWave-specific channel estimation algorithms. In this paper an adaptive algorithm is considered to estimate the mmWave channel parameters. This estimation algorithm is applied to both Single-path and to the multi-path case of the sparse nature of the channel. Simulation results shows that the proposed low-complexity channel estimation algorithm achieves comparable precoding gains compared to exhaustive channel training algorithms.

***Index Terms:** Millimeter wave cellular systems, sparse channel estimation, adaptive compressed sensing, hybrid precoding.*

I. INTRODUCTION

Spectrum of Millimeter wave is in the band of 30 GHz and 300 GHz. This spectrum is used for high-speed wireless communications in the latest 802.11ad Wi-Fi standard. The Federal Communications Commission and researchers bring this into “5G” in future by allocating more bandwidth so that it can deliver higher-quality video and multimedia services. It is considered by the International Telecommunications Union (ITU) as extremely high frequency (EHF) or very high frequency (VHF) band and is used for high-speed broadband wireless communications. In telecommunications domain, it can be used for a variety of services in mobile and wireless networks, because of its high data rates up to 10 Gbps. These waves have shorter wavelengths that can be in range 10 mms to 1 mm so that they have high atmospheric attenuation and also absorbed by gases in the atmosphere. Due to this, the range and strength of the waves can be reduced. Similarly Rain and humidity also affect the performance of the system and reduce signal strength, and the effect is called Fading. Millimeter waves travelled by the line of sight (LOS), so that they may be blocked by physical objects like buildings.

Because of high power consumption of mixed signal components, digital baseband precoding impossible. The design of the precoding matrices is requires complete information of channel state, which is difficult to achieve in mmWave due to presence of large number of antennas and the small signal-to-noise ratio (SNR). Because of the restrictions of hardware new channel estimation and precoding algorithms must be developed. To conquer the radio frequency (RF) hardware restrictions, analog beam forming techniques were proposed in [3]. These methods say that control the phase of each signal to be transmitted by each antenna through a network group of analog phase shifters. Several iterative methods like beam training algorithms were proposed without knowledge of channel at the transmitter. In adaptive beamforming algorithms and multi-stage codebooks were also developed in which the transmitter and receiver jointly design their beamforming vectors. Hence, these methods do not achieve multiplexing gains with multiple parallel streams. The performance of analog strategies such methods in [3], [7]–[9]are not optimal solutions when compared to digital precoding solutions due to constrain on the constant amplitude of analog phase shifters. In order to achieve larger precoding gains, methods in [1]–[2] propose that they seperate the precoding operations as analog and digital. In [11], the joint analog-digital precoder design problem was considered for both spatial diversity and multiplexing systems.

II. SYSTEM MODEL

Consider the millimeter Wave cellular communication system as shown in Fig. 1. The figures shows a Base Station (BS) with antennas and RF chains considered are able to communicate with a single Master Station (MS) with antennas and RF chains as shown in Fig. 2. It is assumed that the number of RF chains at the MSs is less than that of the BS. But we do not use this fact in our model. The BS and MS communicate via dataA. We assume that both the BS and MS have no a priori knowledge about the channel state information. So, in the first half of the paper, the mmWave channel estimation problem is considered and an adaptive CS based algorithm is developed. In the second part the channel state estimation is used to construct the hybrid precoding and decoding matrices.

A. The Mmwave Channel Estimation Problem

By given the mmWave channel model, the mmWave channel estimation is nothing but estimating the different variable parameters of the channel paths, namely the Angle of Arrival, the Angle of Departure, and each path gain. In order to do this accurate and with very low training overhead, the Base Station and Master Station requires careful design of their training precoders . In this section, we utilize propert of the poor scattering of the mmWave channel, and make the mmWave channel estimation problem as a sparseproblem. We will also briefly show how adaptive Compressive Sensing work invokes some ideas for the design of the training precoders,

Then we will propose adaptive algorithms to estimate the mmWave channel methods by utilizing the developed codebook along with evaluating their performance.

B. Sparse Formulation of the mmWave Channel Estimation Problem

Consider the system and mmWave channel models described in Section II. If the BS uses a beam forming vector, and the MS employs a measurement vector to combine the received

Signal, the resulting signal can be written as

C. Adaptive Compressed Sensing Solution

In adaptive CS the training process is divided into a number of stages. The training precoding, and measurement matrices used at each stage are not determined a priori, but rather depend on the output of the earlier stages. More specifically, if the training process is divided into stages, then the vectorized received signals of these stages are

III. ESTIMATION OF MMWAVE CHANNEL ALGORITHMS

Now consider the sparse channel estimation problem. We propose algorithms to estimate the mmWave channel which are adaptively use the hierarchical codebook. First, we consider the problem for the channel models with Rank-one, i.e., when the channel has only one-path. Then the problem is extended to the multi-path case.

A. Estimation Algorithm for Adaptive Channel Single-Path mmWave Channels

For the given the problem in (19), the single-path channel that the vector has only one non-zero element. Hence, estimation of the single-path channel involves determining the location of this non-zero element. For efficient results with low training overhead, we propose Algorithms which adaptively search the non-zero element by using the multi-resolution beamforming vectors designed.

B. Adaptive Channel Estimation Algorithm for Multi-PathmmWave Channels

We now consider second problem i.e. when multiple paths exist between the BS and MS. Because of the nature of poor scattering of mmWave channels, the problem of Channel estimation can be modeled as a sparse compressed sensing problem as discussed previously.

A modified matching pursuit algorithm is used to estimate the Angle of Arrivals and Angle of Departures along with their path gains of the channel, where is the number of dominant paths . Given the problem formulation in (19), the objective is to determine the non-zero elements of with the maximum power. Based on the single-path case, we propose Algorithm 2 to adaptively estimate the different channel parameters

IV. SIMULATION RESULTS

This section explains numerical results that evaluate the performance of the proposed training codebook, adaptive channel estimation algorithm. Consider a single BS-MS link, and then show some results for the mmWave cellular channel model.

In these simulations, we consider the case when there is only one BS and one MS so that there is no interference. The system model and the simulation steps are as follows

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A. Model of the System

For system model we considered hybrid analog/digital system architecture presented in Fig. 2. The BS has antennas,and 10 RF chains, the MS has antennas and 6RF chains. The antenna arrays are ULAs, with spacing between antennas equal to , and the RF phase shifters are assumed to have only quantized phases. Hence, only a finite set of the RF beamforming vectors is allowed, and assumed to be beamsteering vectors, with 7 quantization bits.

B. Model of the Channel

The channel model described in (4), with and a number of paths.

The AoAs/AoDs are considered to be continuous values, i.e., not quantized, and are uniformly distributed in . The system is assumed to operate at 28 GHz carrier frequency, has a bandwidth of 100 MHz, and with path-loss exponent.

C. Simulation Steps

*S*imulations in this section will present spectral efficiency results with different system, and algorithms parameters. To generate these results, the channel parameters are estimated using the algorithms presented in Section V. After estimating its parameters, the geometrical channel is reconstructed and is used in the design of the hybrid precoders and decoders

For the single-path channels, algorithm 1 is used to estimate the channel parameters with AoA/AoD resolution parameter and with beamforming vectors at each stage. For the multi-path case, the parameters will be defined

With each simulation. The training power is determined according to Corollary, with a desired maximum probability of error. Hence, the training power changes based on the parameter, and. Also, the total training power is distributed over the adaptive estimation stages .

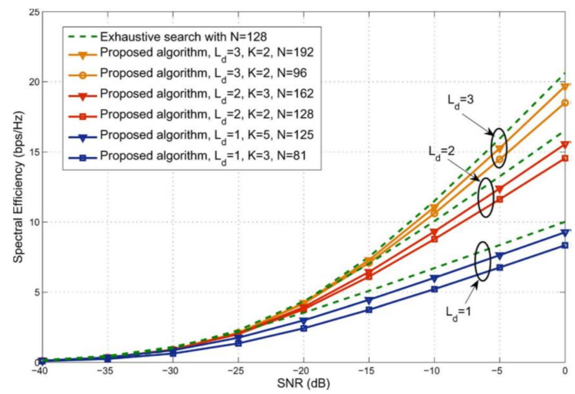

Fig. 1Spectral efficiency achieved when the precoding matrices are built using the mmWave channel estimated by the proposed algorithms in a channel with L=3, and L_d=1, 2, 3.

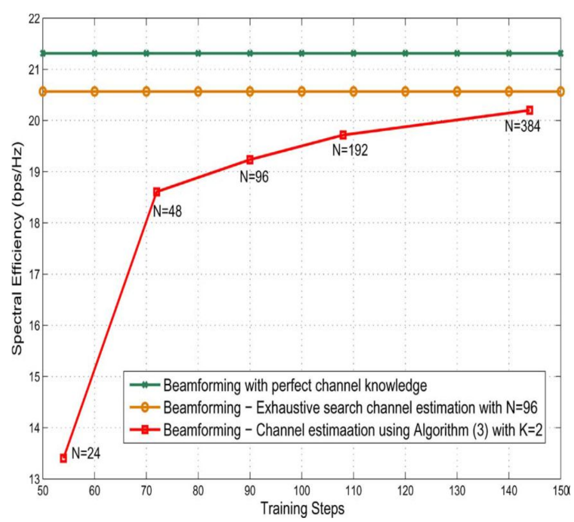

Fig. 2 The improvement of the spectral efficiency with the development of the adaptive channel estimation algorithm is shown and compared with the exhaustive search and perfect channel knowledge cases.

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V. CONCLUSIONS

In this paper, we considered a single-user mmWave system setting, and investigated the design of suitable mmWave channel estimation and precoding algorithms. First, we formulated, and developed a hierarchical multi-resolution codebook

Based on hybrid analog/digital precoding. We then proposed mmWave channel estimation algorithms that efficiently detect the different parameters of the mmWave channel with a low training overhead. The performance of the proposed algorithm is analytically evaluated for the single-path channel case, and some insights into efficient training power distributions are obtained.

Despite the low-complexity, simulation results showed that the proposed channel estimation algorithm realizes spectral efficiency and precoding gain that are comparable to that obtained

by exhaustive search. The attained precoding gains can be also stated in terms of the coverage probability of mmWave cellular systems. For future work, it would be interesting to consider mmWave channels with random blockage between the BS and MS [41], and seek the design of robust adaptive channel estimation algorithms. Besides the channel estimation algorithms developed in this paper assuming fixed and known

array structures, it would be also important for mmWave systems to develop efficient algorithms that adaptively estimate the channel with random or time-varying array manifolds

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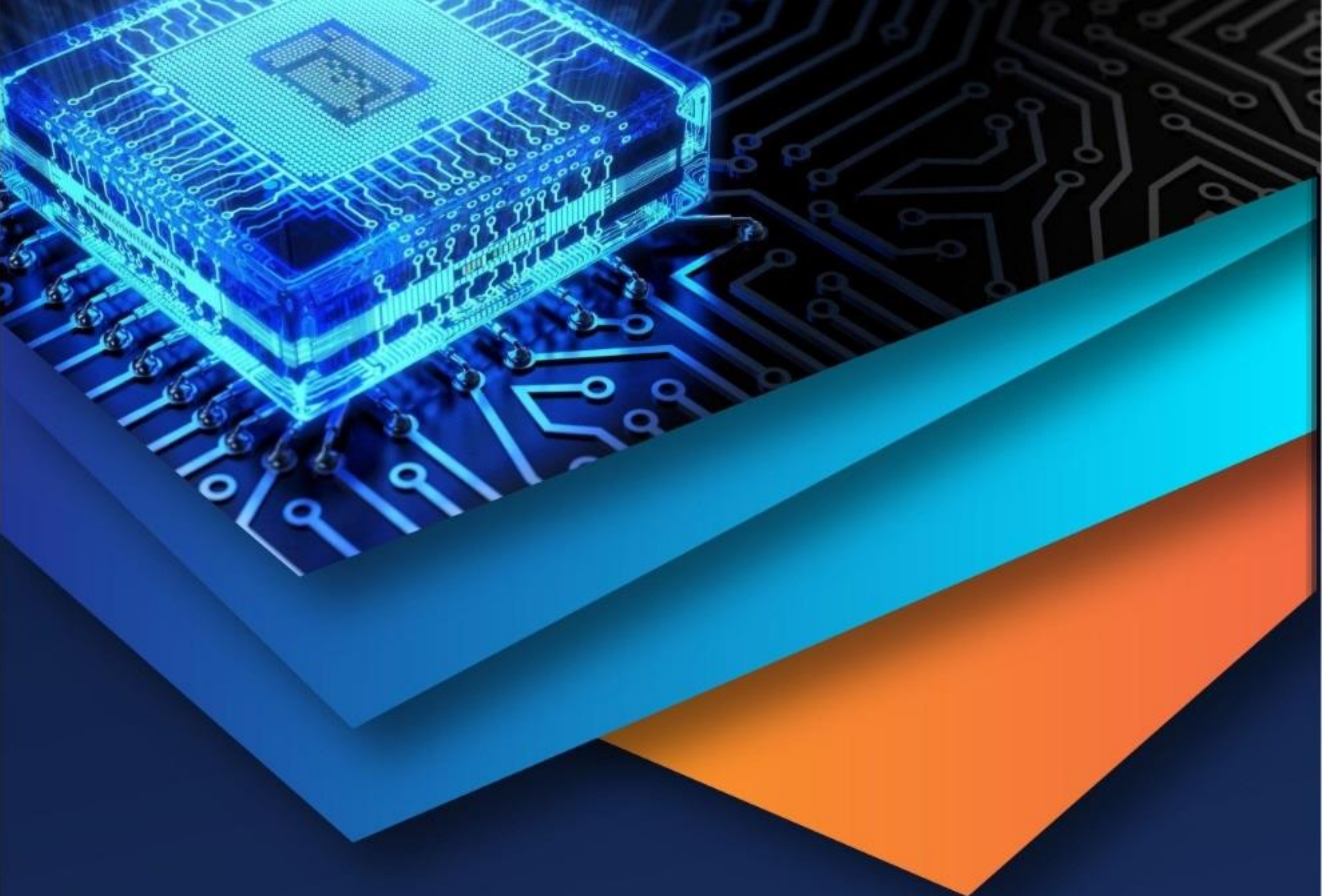

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