MIMO Millimeter-Wave Channel Estimation Using Coalitional Games

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Abstract

In millimeter-wave massive multiple input multiple output (MIMO) antenna systems, channel estimation is a crucial component. In this paper, we propose a virtual channel representation channel estimation method using out-of-band spatial information to reduce training overheads and a cooperative channel allocation method based on coalitional game framework. The proposed cooperative channel allocation method enhances throughput performance in mm-wave small cell networks.

1 Introduction

Large antenna arrays (i.e. Massive MIMO) at both sides the eNodeB (eNB) and UE is a promising technology in order to achieve high-throughput services [Wan12]. Large antenna arrays deal with high path-loss in millimeter frequencies. Further, channel state information (CSI) in terms of channel matrix or beam alignment are needed at the eNB to point the beams in the UE direction. Both strategies are usually acquired by a training sequence [Has03].

In this work, we analyze a channel estimation method that leverages out-of-band measurements to decrease the training overheads for high-speed UEs in mm-wave massive MIMO systems. Therefore, the overlapped virtual beams provide a smaller search space, resulting in reduced channel estimation overheads in mm-wave massive MIMO systems [Rap13]. Since the throughput performance achieved by the proposed channel estimation method inevitably decreases due to inter-cell interference in multiple small cell scenarios, we formulate a coalitional game framework to enhance the system throughput via cooperative channel allocation.

2 System Model

We consider a mm-wave MIMO uplink system with uniform linear arrays (ULAs) conformed by N_t transmitter antennas in the UE and N_r receiver antennas in the eNB. We consider that both the transmitter and the receiver have only one RF chain, hence, only analog beamforming/combining can be applied.

We use $\mathbf{f}$ and $\mathbf{q}$ to denote the beamformer and combiner vector, respectively. The beamformer is defined as follows:

$$\mathbf{f} = \frac{1}{\sqrt{N_t}}[1, ..., \; e^{j(N_r-1)\frac{2\pi}{\lambda}d\cos\phi}]^T, \tag{1}$$

where $\phi \in [-\pi/2, \pi/2]$, is a quantized angle of departure, $\mathbf{f}$ has constant modulus entries, and random phase. In similar fashion the combiner is defined as follows:

$$\mathbf{q} = \frac{1}{\sqrt{N_r}}[1, ..., \; e^{j(N_r-1)\frac{2\pi}{\lambda}d\cos\theta}]^T, \tag{2}$$

where $\theta \in [-\pi/2, \pi/2]$, is the quantized angle of arrival. Then considering a narrowband channel model $\mathbf{H}$, the received signal in the eNB can be modeled as:

$$y = \sqrt{\rho}\mathbf{q}^H\mathbf{H}\mathbf{f}x + \mathbf{q}^H\mathbf{v}, \tag{3}$$

where $\sqrt{\rho}$ is the average transmit power in the training phase, x is the training symbol, and $\mathbf{v}$ is an i.i.d. vector, and $\sim \mathcal{CN}(0, \sigma_0^2\mathbf{I})$ is the noise. A virtual channel representation (VCR) of $\mathbf{H}$ will provide spatial information uniformly spaced over the virtual angles, observed in Figure 1.

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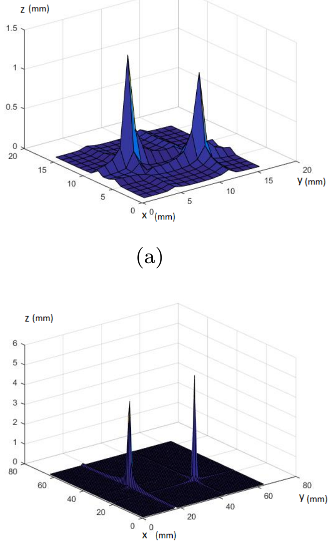

(a)

(b)

Figure 1: Virtual channel matrix for: (a) Sub-6 Ghz with Nr=Nt=16, (b) Mmwave with Nr=Nt=64.

2.1 Millimeter-wave Channel model

We adopt a geometric channel model with L scatterers, where each scatterer contributes to one propagation path. Accordingly, the channel matrix $\mathbf{H}$, is expressed as:

$$\mathbf{H} = \sqrt{N_t N_r} \sum_{l=1}^{L} \alpha_l \mathbf{a}_r(\theta_l) \mathbf{a}_t^H(\phi_l), \qquad (4)$$

where L is the number of paths, α_l represents the complex path gain of the l-th propagation path, $\theta_l \in [-\pi/2, \pi/2]$, and $\phi_l \in [-\pi/2, \pi/2]$ denotes the AoA and AoD of the L-th path at transmitter and receiver, respectively. The $\mathbf{a}_t(\cdot)$ and $\mathbf{a}_r(\cdot)$ vectors denote the array response vectors for transmiting and receiving antenna arrays, respectively.

3 Multicell Analysis

Lets consider an Orthogonal Frequency Division Multiple Access (OFDMA) multicell system, as is shown in Figure 2. We assume that in every cell there is a small microwave cell station and millimeter-wave small station located in the same position. Consider the multicell network architecture depicted in Figure 2 where the UE1 is located in the eNB2 coverage area border, such that this user must deal with handoff management and interference from neighboring cells. In order to overcome these problems, we propose a method based on cooperative model using coalitional games between the concerned eNBs.

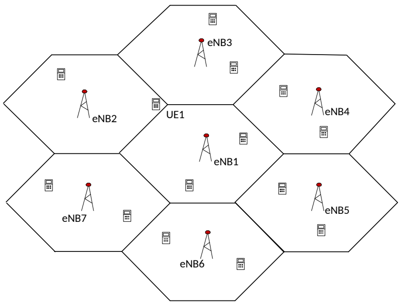

Figure 2: Multicell network architecture.

3.1 Coalitional Game: System Model

The main goal is to deal with interference from neighboring millimeter-wave small cells (MMWSC) in the border coverage area by forming coalitions. Using coalitional game theory, we denote as B the set of all partitions $G_{\mathcal{N}}$ of $\mathcal{N}$, this problem can be modeled as coalitional game in partition form with transferable utility as the pair $(\mathcal{N}, v)$ where $\mathcal{N}$ is the set of players in the game, and a value function $v(S, G_{\mathcal{N}})$ assigning a real value to each coalition S. We also assume that $v(\emptyset) = 0$. The function describes how much collective payoff a set of players can gain by forming a coalition, and the game is sometimes called a value game or a profit game. Thus, the definition above imposes a dependence on the coalitional structure $\mathcal{N}$ when evaluating the value of $S \subseteq \mathcal{N}$. Therefore the utility achieved by the coalition S can be expressed in terms of the channel rate as:

$$\mathcal{U}(\mathcal{S}, G_{\mathcal{N}}) = \sum_{i \in \mathcal{S}} \sum_{l \in \Gamma} \alpha_i^l \, \log_2 \Big(1 + \frac{\rho_{i,l} \mathbf{q}_{i,l}^H \mathbf{H}_{i,l} \mathbf{f}_{i,l} \mathbf{f}_{i,l}^H \mathbf{H}_{i,l}^H \mathbf{q}_{i,l}}{\sigma_o^2 + \hat{\mathbf{I}}_S}\Big), \qquad (5)$$

Given the power cost and utility function for any coalition $S \in \mathcal{N}$, we can define the value of any coalition, i.e., the total benefit as:

$$v(\mathcal{S}, G_{\mathcal{N}}) = \begin{cases} |S| \; \mathcal{U}(\mathcal{S}, G_{\mathcal{N}}) & if \ \rho_S \leq \rho_{lim} \\ 0 & otherwise, \end{cases} \qquad (6)$$

We can define the payoff of a MMWSC $i \in S$ as:

$$x_i = \frac{1}{|S|} \left(v(\mathcal{S}, \pi_{\mathcal{N}}) - \sum_{j \in \mathcal{S}} v(\{j\}, G_{\mathcal{N}}) \right) + v(\{i\}, G_{\mathcal{N}}), \qquad (7)$$

3.2 Proposed Algorithm

For the stated coalitional game it is important to notice that due to power constraint requirements, the grand coalition seldom forms. Therefore, cooperation will occur when the interferring MMWSCs are closely

Algorithm 1 Proposed MMWSC cooperation algorithm

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Step 1: UE interference sensing
  The UE sense the interference $UE_{int}$, once it overpass a threshold $I_{thr}$, the UE feedback the information to its attached eNB in order to initiate the cooperation process, thus:
if $UE_{int} \geq I_{thr}$ then
    Step 2: Coalitional Game Starts
      At the beginning when players are not cooperating $G_{\mathcal{N}} = \{1, ..., \mathcal{N}\} = \{S_1, ..., S_{\mathcal{N}}\}$.
    Three stages in each round of the algorithm
      Stage 1 - Discovering Neighbors:
        • Each MMWSC discovers the neighboring coalitions.
      Stage 2 - Recursive Coalition Formation:
      repeat
        • Each MMWSC establishes negotiations with discovered neighboring FAPs. Each MMWSC create a list of the feasible coalitions which ensure $\rho_S \leq \rho_{lim}$, Where $\rho_S$ is the power cost needed to form a coalition S and $\rho_{lim}$ is a maximum tolerable power cost for every coalition S. The payoff for the feasible coalitions is computed and each MMWSC joins to the coalition which ensures the maximum payoff.
      until convergence to a stable partition in the recursive core.
      Stage 3 - Inner-coalition scheduling:
        • The scheduling information is gathered by each MMWSC $i \in S$ from its coalitions members, and transmitted within the coalition $S$ afterwards.
end if
Step 3: High Speed mmWave Communications
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located in a way that $\rho_S \leq \rho_{lim}$. Finding an optimal coalitional structure for games in partition form has been studied in [Hua06] and [Pan11]. In this manuscript we will apply the concept of *recursive core* as it was done in [Pan11].

3.3 Preliminary Numerical Results

In order to explore the performance of the proposed method, Sub 6-Ghz channel was set with 16 transmitter antennas and 16 receiver antennas, whereas for the mm-wave channel the systems was set with $N_r = N_t = 64$, $N_r = N_t = 32$, and $N_r = N_t = 16$ antennas. It can be seen in Figure 3 how the spectral efficiency changes according to different SNR values.

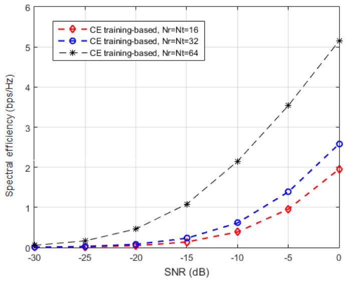

Figure 3: Rate achieved by CE training-based over different SNR values.

4 Conclusions and Future Work

In this work, we proposed a channel estimation method based on coalitional game for a multicell case that improves the throughput. The prior based on an algorithm that improves intercell interference. As future works we will analyze in the single cell case how the analyzed method performs in different SNR scenarios, the computational complexity, user equipment (UE) mobility environment, and BER analysis.

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