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Waterfilling in MASSIVE MIMO Network

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***Abstract*-Here we discuss the a general game-theoretical framework for power allocation in the wireless cellular network ,where multiple access points or small base stations send independent coded information to multiple mobile terminals through orthogonal Code division multiplexing channels. Here in the game-theoretical study, a Nash equilibrium exists, and if so, whether the network operates efficiently at the NE. For independent continuous fading channels, we show that this power allocation problem can be a potential game, and hence efficiently solved. In order to reach the Nash Equilibrium, we propose a distributed water filling based algorithm for a MASSIVE MIMO system to increase the system capacity.**

Key Words– water filling ,Nash equilibrium Single Input Single Output (SISO), Multi Input Multi Output (MASSIVE MIMO), space time multiple access (STMA), 3GPP standard. Signal to Noise Ratio (SNR), Shannon capacity

I. INTRODUCTION

The wireless communication system is coupled with multiple transmit and receive antennas and Orthogonal Frequency-Division Multiplexing (OFDM), is regarded as a one of the solution for enhancing the data rates of wireless communication systems operating in frequency-selective fading environments. Recent research result shows that Multiple-Input and Multiple-Output (MASSIVE MIMO) [2]could be used to increase the capacity by a factor of the minimum number of transmit and receive antennas compared with a Single-Input Single-Output (SISO) system with flat fading or narrowband channels, while OFDM can increase diversity gain and mitigate inter-symbol interference on a time-varying multi-path fading channel. When the channel parameters are known at the transmitter, the capacity of MASSIVE MIMO OFDM systems can be further increased by giving the power to the transmitter according to the to the water-filling algorithm. At transmitters, the transmitted signals of different carriers are usually eigen beam formed independently to orthogonal modes of spatial channels at every sub-channel in MASSIVE MIMO OFDM systems, which can be formed via spatial filtering according to the Singular Value Decomposition (SVD) of channel matrix at transmitters. For a MASSIVE MIMO OFDM system configured with low rate space-time codes, it will be difficult to conduct adaptive power allocation as a large number of eigenmodes exist, compared with data symbols carried by one MASSIVE MIMO OFDM symbol. Also, as one space-time codeword is carried by many eigenmodes at multiple carriers, it is also difficult to determine the modulation order of data symbols encoded in a space-time codeword. Therefore, these eigenmodes can be seen as the simple generalization of their counterparts of a MASSIVE MIMO system in single-carrier transmission for conveniently analyzing system capacity, but not reflect the fact of one space-time codeword being carried by multiple sub-channels. An improved water-filling power providing scheme is also proposed to determine the power allocation and its correspondent bit number for reason of complexity or poor performance of existing schemes. The classical water-filing power allocation scheme is only optimal to maximize system capacity but with a great deal of residual power by reason of discrete modulation orders. Hence, many improved water-filling schemes or other power allocation schemes are given in recent research literatures, such as iterative water-filing algorithms, sub-channel group water-filling scheme, greedy algorithms, iterative bits power allocation, and so on. Among these schemes, only greedy power allocation is optimal to maximize the transported total bits but at a cost of calculation overhead. Moreover, similar to greedy algorithm, other schemes are conducted in iterative wise, and their convergences have significant effects on system performance. Whereas, the improved water-filling power allocation scheme can be done in two steps and can also achieve the maximized transported bits. In this scheme, the classical water-filling method is firstly adopted to determine the optimal power allocation and corresponding bit number for every eign value. The article is organized as follows. In section II, discusses the MASSIVE MIMO capacity and apply the water filling algorithm to increase the power. Section III, we describe the water filling In section IV, we conclude our discussion with the results.

II. MASSIVE MIMO CHANNEL CAPACITY

Lets consider a MASSIVE MIMO system with nr receive and n_t transmit antennas. It is now well accepted fact that we can increase capacity without increasing the bandwidth and transmit power rather by just putting more antennas at transmitter and receiver side. The most important part to understand and deal the MASSIVE MIMO capacity is the channel matrix. Considering the impulse response between the j^{th} ($j = 1, 2 ..., n_t$) transmit antenna and the i^{th} ($i = 1, 2, ..., n_r$)

Receive antenna by $h_{i,j}(\tau,t)$, the MASSIVE MIMO channel is given by the $n_r \times n_t$ matrix H(τ , t) with

$$H(\tau,t)=\begin{bmatrix} h_{1,1}(\tau,t) & h_{1,2}(\tau,t) & .... & h_{1,n_t}(\tau,t) \\ h_{2,1}(\tau,t) & h_{2,2}(\tau,t) & .... & h_{2,n_t}(\tau,t) \\ . & . & ..... & . \\ . & . & ...... & . \\ . & . & .... & . \\ h_{n_r,1}(\tau,t) & h_{n_r,2}(\tau,t) & .... & h_{n_r,n_t}(\tau,t) \end{bmatrix} \quad (6)$$

The vector $\left[h_{1,j}(\tau,t) h_{2,j}(\tau,t)\ \ h_{3,j}(\tau,t)\ \ ......\ \ h_{n_r,n_t}(\tau,t)\right]^T$ is the spatio-temporal signature or channel induced by the j[th] transmit antenna across the receive antenna array. The random channel we have used is the Rayleigh model. In frequency domain, the channel is approximated by a complex matrix having the independent, identically distributed (iid) entries with zero mean and unit variance. A generalized capacity formula and a capacity lower-bound formula are mentioned below. This is for any (n_r, n_t) MASSIVE MIMO system.

$$C = \log_2\left[\det\left(I_{nr} + \left(\frac{\rho}{\eta_t}\right)HH^{\dagger}\right)\right] b/s/Hz \qquad (7)$$

In this equation, "det" means determinant, Inr means n_r x n_t identity matrix and "†" means transpose conjugate. The capacity lower bound for the (n, n) case in terms of the independent chi-squared variable with two-degrees of freedom is as follows.

$$C > \sum_{k=1}^{n} \log_2\left[1 + \left(\frac{\rho}{\eta_t}\right)\psi_{2k}^2\right] b/s/Hz \qquad (8)$$

The capacity formula for optimum ratio combining or receive diversity (n_r= n_t = n) is given as [1].

$$C = \log_2\left[1 + \rho.\psi_{2n}^2\right] b/s/Hz \qquad (9)$$

It is worth noting from the results shown in Fig. 2 that capacity of wireless network increases as we increase the number of antennas. This section describes the some very important properties of channel matrix H [5]. We describe in this section some statistics of H like singular value decomposition. By diagonalizing the product matrix HH† using eigen value decomposition, the matrix product is written as [8]

HH† = E^E† (10)

Where E is the eigenvector matrix with orthonormal columns and ^ is a diagonal matrix with the eigen values on the main diagonal. Using this notation, the capacity of MASSIVE MIMO channels can be written as:

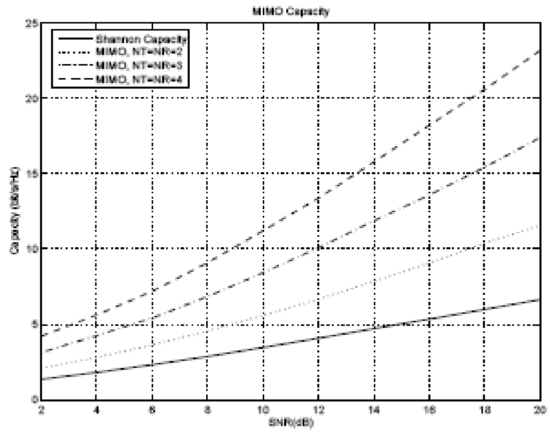

Fig. 1. MASSIVE MIMO Channel Capacity

$$C = E_h\left\{\log_2\left[\det\left(I_{nr} + \frac{\rho}{\eta_t} E \wedge E^{\dagger}\right)\right]\right\} \qquad (10)$$

In general, the rank of the channel matrix is given by

$$rank(H) = k \leq \min\{n_r, n_t\} \qquad (11)$$

Using the equation (10), together with the fact that the determinant of a unitary matrix is 1, the capacity expression can be written as:

$$C = E_H\left\{\sum_{i=1}^{k} \log_2\left(1 + \frac{\rho}{n_t}\lambda_t\right)\right\} \qquad (12)$$

$$= E_H\left\{\sum_{i=1}^{k} \log_2\left(1 + \frac{\rho}{n_t}\sigma_t\right)\right\} \qquad (13)$$

Where λ_i are the eigen values of the diagonal matrix Λ and σ_i are the squared singular values of the diagonal matrix $\sum$.When the channel is known at the transmitter, the maximum capacity of a MASSIVE MIMO channel can be achieved by using the water-filling algorithm [3] on the transmit covariance matrix. The capacity is then given by:

$$C = E_H\left\{\sum_{i=1}^{k} \log_2\left(1 + \varepsilon_i \frac{\rho}{n_t}\lambda_t\right)\right\} \qquad (14)$$

$$= E_H\left\{\sum_{i=1}^{k} \log_2\left(1 + \varepsilon_i \frac{\rho}{n_t}\sigma_t\right)\right\} \qquad (15)$$

Where ε_i is a scalar, representing the portion of the available transmit power going into the ith channel. Hence, by using the water-filling algorithm we can meet the total power constraint.

III. WATER FILLING POWER ALLOCATION ALGORITHM

Based on adaptive modulation (MA) margin adaptive principals, link adaptation techniques can be implemented from two aspects, i.e., power allocation under total transmit power constraint for transported bits, and bits allocation under total transmit bits for minimum transmit power, respectively. In this study, under the given total power and target Bit Error Ratio (BER), we only consider how to conduct power allocation to orthogonal eigen modes in order to maximize transmit bits. The transmit power for AWGN channel to transmit c number of bits information with M-QAM modulation scheme, is given by

$$P(c) = \frac{\sigma^2}{3}\left[Q^{-1}\left(\frac{P_e}{4}\right)\right]^{-2}(2^e - 1) \qquad (16)$$

is denoted as complementary error function. Then, for given transmit power, the bits to be transported is given by the AWGN channel, can be derived according to Eq. 16, as shown in the following formula

$$c = floor\left[\log\left(1 + \frac{3P}{\sigma^2}\left(Q^{-1}\left(\frac{P_e}{4}\right)\right)^2\right)\right] \qquad (17)$$

In order to have maximum transported total bits, a water-filling power allocation scheme is given on the base of classical water filling schemes. According to the scheme, the power and bit allocation are conducted in two steps. Firstly, an initial power allocation is shown by classical water-filling scheme, That is, the first step is executed to initially allocate the power for different orthogonal eigenmodes according to the classical water-filling scheme. Then, after determining the transported bits at channel eigenmodes, the residual power is reallocated among these eigenmodes to transport additional bits.

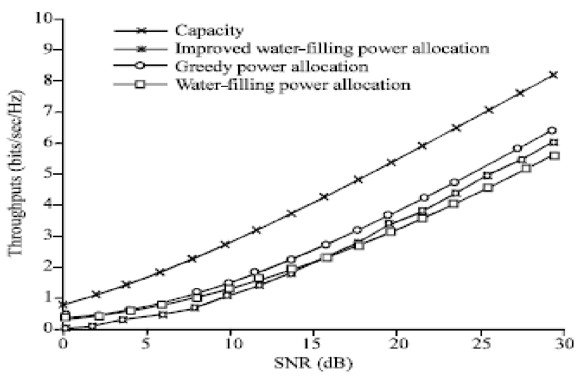

Fig. 2.Throughput of a with waterfilling algorithm

IV.CONCLUSION

This paper we have developed an understanding and described the power allocation in a wireless cellular network as a game theory based on the water filling power allocation in order to enhance the capacity of MASSIVE MIMO systems with different channel assumptions. Here each transmitter decides the distribution of power to the several independent fading channels. We studied the existence and uniqueness of Nash Equilibrium. The probability of having a unique equilibrium is equal to 1. Also, an improved water-filling scheme is proposed for determining the optimal transmit powers for orthogonal eigenmodes. Results show that improved water-filling scheme can obtain good results, with comparison to classical water-filling schemes

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