Adaptive Resource Allocation in MIMO-OFDM Communication System

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Abstract— Multiple Input and Multiple Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM) system have the potential to achieve very high capacity depending on the propagation environment. The objective of this paper is the adaptive resource allocation in MIMO-OFDM system using the waterfilling algorithm. Water filling solution is implemented for allocating the power in order to increase the channel capacity. The total system capacity is maximised subject to the constraints on total power, signal to noise ratio, and proportional fairness. Channel is assumed as a flat fading channel and the comparison is made for different 2x2, 2x3, 3x2 and 4x4 MIMO-OFDM systems using waterfilling algorithm with allocated power. Also in order to prove that the MIMO-OFDM with waterfilling algorithm provides the best performance a comparison with various SISO –OFDM is done.

Keywords: OFDM, MIMO, Water filling algorithm channel capacity, signal to noise ratio (SNR), power allocation

I. INTRODUCTION

Wireless communications, is by any measure, the fastest growing segment of the communications industry. Cellular systems have experienced exponential growth over the last decade. Taking advantage of existing technologies and discovery of new technologies that supports high data rates are being carried all over the world to meet the customer demands. The next generation wireless network will be required to support a wide range of high data rate application ranging from video transfer to file download. Two technologies which have gained much interest for development in these future networks are the use of Multiple-Input Multiple-Output (MIMO)systems which utilize multiple antennas at the transmitter and receiver, and Orthogonal Frequency-Division Multiplexing (OFDM). High rate transmission is limited in part by frequency selective fading and multipath propagation which give rise to problems such as inter symbol interference (ISI). The use of MIMO in wireless channels has been shown to give a large increase in capacity [1]. It is especially useful in mobile networks due to its ability to use multipath propagation (a rich scattering environment) to its advantage. By transmitting using spatial multiplexing the number of users that can be serviced using a single base transceiver station (BTS) can also be increased. OFDM is a modulation technique that splits a given frequency-selective broadband channel into a large number of flat-fading sub channels and has received attention due its ease of equalization and resistance to ISI. It is used in protocols for wireless network systems such as IEEE802.16a. In general, a lot of paths are arrived at the receiver in wireless communications. In the time-domain signal processing, the complexity for the multi-path equalization is exponentially increased as the number of paths increases. Therefore, if the complexity is limited, the performance is degraded by the residual inter-symbol interference (ISI). On the other hand, the multi-path fading is changed as a flat fading on each subcarrier of OFDMA because OFDMA consists of narrow-band subcarriers, and a cyclic condition is satisfied by a guard interval insertion. Then, a severe multipath fading can be equalized linearly in the frequency domain in OFDMA and no ISI appears. By this property, OFDMA is often used for transmission in the severe multipath fading channel compared with FDMA (frequency division multiple access) or TDMA (time division multiple access) which have relatively wide bandwidth. In addition, each subcarrier can flexibly be allocated to users according to their instantaneous channels. This flexible subcarrier allocation enables a larger channel capacity of the system, and it is suitable to combine OFDMA with MIMO (multiple input multiple output) which also aim at a capacity enhancement. But also introduces new problems relating to how these frequency and space sub channels are efficiently divided among users. The allocation of space and frequency, along with time, power and bits, is known as resource allocation and is a vital part of designing networks [2], [3].The focus of this paper is to increase the capacity of the MIMO-OFDM communication system. To increase the capacity a water filling algorithm is introduced in the system. And to prove that MIMO with water filling is best, a comparison with various SISO and MIMO systems are done.

This paper is organized as follows: Section II includes related works. Section III describes the concept of SVD and Section IV describes the concept of waterfilling theorem. Section V presents the experimental results and discussion. Section VI gives the snapshot description. The paper is concluded in section VII

II. RELATED WORK

Two classes of optimization techniques have been proposed in SISO/MIMO-OFDMA literature: margin adaptive (MA) [4] and rate adaptive (RA) [5]. The margin adaptive objective is to achieve the minimum overall transmit power at the Base Station (BS). The rate adaptive objective is to maximize each user error-free capacity with a total transmits power constraint. In [5], the margin adaptive resource apportionment was tackled. In [6], the rate adaptive problem was probed, wherein the destination was to maximize the total data rate over all users subject to power and BER constraints. Then, this was extended in [7] to achieve almost idea proportional rate distribution. For such a system, in [8] a lower complexity has been formulated and in [7] a priority based sequential scheduling criteria to enhance system
capacity with largely reduced fairness has been introduced. The tradeoff between capacity and fairness has been discussed in [4]. But, these algorithms hardly ever consider rate fairness among users or do not have a flexible controllability on rate fairness. In [19], the system capacity is maximized by subcarrier reorganization with a total power constraint. However in [9], BER constraint is not taken into account, which is a main parameter in deciding the efficiency of the resource apportionment scheme. It will be desirable in many applications to have a tradeoff strategy between capacity and fairness for lending wireless resources.

III. SINGULAR VALUE DECOMPOSITION

The SVD technique decouples the channel matrix in spatial domain in a way similar to the DFT decoupling the channel in the frequency domain. The channel matrix H is the T x R channel matrix. If H has independent rows and columns, SVD yields:

$$H = UV^H$$

Where U and V are unitary matrices and Vh is the hermitian of V. U has dimension of R x R and V has dimension of T x T. Σ is a T x R matrix. If T = R, then Σ become a diagonal matrix. If T > R, it is made of R x R diagonal matrix followed by T – R zero columns. If T < R, it is made of T x T diagonal matrix followed by R – T zero rows. This operation is called the singular value decomposition of H. In case, where T ≠ R, The number of spatial channels become restricted to the minimum of T and R. If the number of transmit antennas is greater than the receive antennas (T > R), U will be an R x R matrix, V will be a T x T matrix and Σ will be made of a square matrix of order R followed by T-R zero columns[10]

IV. CONCEPT OF WATERFILLING ALGORITHM

Waterfilling is a metaphor for the solution of several optimization problems related to channel capacity. The simplest physical example is perhaps the case of spectral allocation for maximal total capacity under a total power constraint [12].

Many engineering problems that can be formulated as constrained optimization problems result in solutions given by waterfilling structure the classical example of which is the capacity achieving solutions for the MIMO channel. The problem of jointly designing the transmitter and the receiver for communication through MIMO channel also results in a Waterfilling solution. The well – known classical waterfilling solution solves the problem of maximizing the mutual information between the input and the output of a channel composed of several sub channels ( such as a frequency – selective sub channels arising from the use of multiple antennas at both sides of the link ) with a global power constraint at the transmitter. This capacity – achieving solution has the visual interpretation of pouring water over a surface given by the inverse of the sub channel gains hence the name waterfilling or waterpouring [12].

A. Water filling capacity of MIMO channel

When the channel knowledge is absent at the transmitter, the individual sub channels are not accessible. So the equal power allocation in all the sub channels is logical under this scenario. When the transmitter has perfect knowledge of the channel, the waterfilling method theorem so the division of total power in such a way that a greater portion goes to the sub channels with higher gain and less or ever none to the channels with small gains.

The sub channels with lower gain i.e. those with higher noise for which no power is allocated at all refer to those sub channels which are not used for transmitting any signal during the transmission. One objective of this algorithm is to allocate power across the channel so as to maximize the total capacity. This power allocation is subject to the constraint that the sum of the power poured into all sub channels is equal to PT, the total power available to the transmitter. The relative channel strengths and the amount of power to allocate to each channel is determined by knowledge of the channel matrix, H.

We use the Eigen decomposition of H to obtain as, $H(\text{r-by-t}) = UD\Sigma V^H$

Where, $UU^* = I = VV^*$

D = diagonal matrix $\lambda_1, \lambda_2, \lambda_3...\lambda_n$ with $\lambda_i$ as the positive square root of ith Eigen value and $i = 1$ to $n$ non zero $\lambda$ values.

The first step is to determine the parameter $\mu$. The parameter $\mu$, is a mathematical parameter, used to determine the power assigned to each of the sub channels of the composite MIMO channel. After determining the $\mu$, the square of the inverse of Eigen values are compared with $\mu$.

If the square of the inverse of ith Eigen value is greater than $\mu$, i.e if $1/\lambda_i^2 \geq \mu$, then that ith eigen channel is too weak to be used for the communication process. The last two sub channels in the above illustrated example of a (7 - by - 7) MIMO channel are such eigen channels which are not used for transmitting any signal at that point of time. Such channels are said to be switched off and they are put away from the communication process which means that those particular sub channels are not allocated with any transmitting power.

Once the total available power, PT and the gains of the parallel sub channels are known, the optimum power allocated to the ith sub channel is,

$$P_i = \left(\mu - \frac{1}{\lambda_i^2}\right)$$

If this quantity $P_i$ is positive then the power is allocated to the ith sub channel otherwise, the sub channel is left unused. The waterfilling parameter ‘$\mu$’ is determined iteratively by the total power $P_T$, such that $\mu$ satisfies the following equation,

$$P_T = \sum_{i=1}^{m} \left(\mu - \frac{1}{\lambda_i^2}\right)$$

$I= 1,2,.....m$; where $m$ is the number of sub channels that have survived after checking the above conditions and are to be used for transmission of the signal. Now the capacity of MIMO channel with waterfilling can be expressed as

$$C = \sum_{i=1}^{n} \log_2 \left[1 + \left(\frac{\rho_i}{\sigma^2}\right) \cdot \rho_i^2\right] \text{ bps / Hz}$$

Above equation enables the visualization of the MIMO channel as a number of parallel SISO pipes with gain equal. Therefore to the respective Eigen values and its enables as
to understand that the waterfilling capacity for MIMO channels is the sum of the capacities of the SISO equivalent parallel sub channels, obtained from performing SVD on MIMO channel matrix. If the channel is known at the transmitter, the capacity can be enhanced by using the good channels i.e. those with the highest gain by applying an unequal power distribution.

B. Step to power allocation with waterfilling algorithm

Summary of steps involved in the waterfilling power allocation to the MIMO subchannels [12]

1. The first step is to determine the waterfilling parameter or threshold, \( \mu \) which is also shown as water level. The \( \mu \) is just a mathematical parameter used to determine the power allocated to each of the eigen channels.

2. After determining \( \mu \), the inverse of eigen values of the matrix \( H \) is compared with the threshold.

3. Now if \( 1/\lambda_2 \geq \mu \) then, the gain of the ith eigen channel is too small and this eigen channel will not be considered for communication, the last two eigen channel.

4. Assuming the case of a square dimension of MIMO channel, i.e. \( r=t \) and also \( \lambda_1 \geq \lambda_2 \geq \lambda_3 \ldots \geq \lambda_n \). And also consider that m eigen values have survived after the above described procedure.

5. Once the total available power, \( P_T \) and the gains of the parallel sub channels are known, the optimum power allocated to the ith sub channel is

\[
\mu_i = \left[ \mu - \frac{1}{\lambda_i} \right]
\]

And the power allocated to each of these eigen channels, \( P_i \) is determined by the waterfilling rule such that the above equations are satisfied. When it is positive then the ith sub channel otherwise, the sub channel is left unused. The waterfilling parameter \( \mu \) is determined next part. Under ideal conditions, the information theoretic capacities of a MIMO system grows linearly with the minimum of transmit and receive antennas. However, various measurements show that realistic MIMO channels show a significantly lower capacity. This reduction of capacity is due to the spatial correlation of the MIMO channel coefficients. But here with waterfilling algorithm the capacity increases with correlation as proved before as MIMO capacity analysis with respect to linear increment in number of transmitting and receiving antennas for fixed values of SNR with water filling power allocation algorithm assumed[11][12].

V. EXPERIMENTAL RESULTS AND DISCUSSIONS

A. Simulation Parameters

<table>
<thead>
<tr>
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<td>( 1=1,2=2,3=3,4=4 )</td>
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Table 1: Simulation Parameters

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B. Simulation Snapshots

![Fig. 1: Power allocation in the existing system](image1)

![Fig. 2: Power allocation in MIMO-OFDM system with proposed water filling algorithm](image2)

![Fig 3: Comparison of the capacity of the existing system and the proposed system](image3)
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VI. SNAPSHOT DESCRIPTION

Figure 1 and Figure 2 shows the power allocation in the MIMO OFDM system. From the figure it is clear that the proposed MIMO-OFDM system with water filling algorithm (Fig 2) requires lesser amount of power compared to the existing system as shown in Figure 1. Figure 3 comparison of the capacity for the existing system and the proposed system. From the figure it is clear that there is an improvement in capacity of MIMO-OFDM channel when the water filling solution is implemented to achieve capacity maximization is used to allocate different power to the sub channels.

Figure 4 illustrate the channel capacity versus SNR for different MIMO-OFDM systems. The graph shows that the capacity of the MIMO-OFDM channel increases as the number of antennas used at both the transmitter and the receiver increases.

Figure 5 represents the power spectral density (PDF) versus SNR of different MIMO-OFDM systems. These two graphs depict that the 4x4 MIMO systems provides better channel capacity and PDF than any other combinations. This indicates that a higher order MIMO system increases the system performance. It is interesting to note that the system performance remains almost the same when the number of transmitter and receiver antennas is altered (2x3 MIMO and 3x2 MIMO systems). Figure 6 gives the comparison between various MIMO and SISO systems. This graph shows that MIMO System with water filling algorithm has the better performances compared to the all other systems.

VII. CONCLUSION

In this paper, adaptive resource allocation in MIMO-OFDM system is done by using a water filling algorithm. By using the water filling solution it is clear that the power required is less compared to the existing power allocation algorithm. Also channel capacity of MIMO-OFDM systems is estimated using water filling algorithm The use of multiple antennas on both the transmitter and receiver side of a communication network have shown to greatly improve the efficiency of wireless system. The mean capacity allocation in wireless cellular network based on the water filling power allocation in order to enhance the capacity of MIMO-OFDM system with different channel assumptions. It is observed that maximum power is allocated to the channel having greater gain. The graphs of capacity versus SNR, shows that the capacity of the MIMO-OFDM channels increases as the number of antennas used at the transmitter and receiver increases.

REFERENCES


