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A Review on Channel Capacity Analysis in MIMO-OFDM System

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Abstract— **The growing demand on wireless communication services has created the necessity to support higher and higher data rate. Energy efficiency is an active research topics in the field of wireless communications. This paper presents an analytical literature survey related to the energy efficiency in the MIMO-OFDM system**

Keywords- **MIMO-OFDM, water filling.**

I. Introduction

Wireless communication turns to the era of green. This is not only because of the exponential traffic growth in the popularity of the smart phone, but also the limited energy source with ever higher prices. Energy efficiency, as a result, becomes one of the major topics in the research of wireless communications [1] and plenty of research projects either government funded or industrial funded start to investigate the energy efficient solutions for the wireless network as well as the sustainable future of the wireless communications. Meanwhile, multiple input multiple output (MIMO), especially downlink multiuser MIMO (also called MIMO broadcasting channels), has become a key technology in the cellular networks due to its significant spectral efficiency improvement. Therefore, studying the EE of the MIMO BC is a critical issue.

The Energy efficiency is in general defined as the capacity divided by the power consumption, which denotes the delivered bits per-unit energy measured in bits per-Joule.

MIMO communication systems exploit the degrees of freedom introduced by multiple transmit and receive antennas to offer high spectral efficiency. In narrowband channels, when channel state information is available at the transmitter and instantaneous adaptation is possible, the capacity achieving distribution is found by using the well-known water-filling algorithm [2] [3]. With only average power constraints, a two-dimensional water-filling in both the temporal and spatial domains has recently been shown to be optimal [4] [5]. By studying the empirical distribution of the eigenvalues of Gaussian random matrices [2], two-dimensional water-filling for Rayleigh MIMO channels [4] [5] can be transformed into one-dimensional water-filling for a time-varying SISO channel [6]. Although the ergodic capacity in MIMO Rayleigh fading channels is well understood, the capacity in MIMO Rayleigh fading channels with shadowing effects has not been evaluated. Furthermore, while [2]-[5] have studied either spatial or space time water-filling, the capacity gain of space-time water-filling over spatial water-filling has not been studied.

The problem of maximizing the mutual information between the input and the output of a channel composed of several sub channels with a global power constraint at the transmitter [7, 8, 9] can be solved with the help of water filling algorithm.
This capacity enhanced way can be seen as pouring water over a surface given by the inverse of the sub channel gains, hence the name water filling or water pouring.
This algorithm has been considered in many works to design well-organized communication

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model [10, 11, 12]. There are, however, other completely different problems that result in similar water filling solutions. Generally, when the transmitter and receiver are jointly planned for communications through multiple-input multiple-output channels, these types of way are typically appearing [13]. Possibly the most common of such difficulties is the minimization of the sum of the mean square errors of the different sub-channels present in a MIMO channel, resulting in a water filling solution [14, 15, 16, 12, 17, 18] (for frequency- selective single-input single-output channels, similar types of solution were obtained already in the sixties [19]). If the system is planned to minimize the determinant of the MSE matrix, the classical capacity-achieving water filling result is again obtained [20, 18] (this is because of the direct relation between the determinant of the mutual information and the MSE matrix [21]). Water filling help in maximization of the minimum signal to interference-plus-noise ratio among the sub channels also results in a water filling solution [13]. In the literature [22], the minimization of the average bit error rate over a set of parallel sub channels was extensively treated obtaining a water filling result. In literature [23], minimum BER were obtained for the case of defective channel knowledge at the transmitter end, with a water filling power allocation. Newly, the problem of joint transmit-receive design to attain minimum average BER in MIMO channels has been solved independently in the paper [24] and [13], obtaining a solution that includes the same water filling algorithm as in the minimization of the trace of the MSE matrix.

The water filling algorithm recommended in the past was very simple to determine as calculations require only a single water level and a power constraint. As the calculation is parameterized with a single water level, the problem reduces to obtaining the water level such that the power constraint is satisfied with equality.

The water filling algorithm can be classified into iterative algorithms and exact algorithms, In order to find the exact value of the water level. The iterative procedure is more practical and get close to the exact value as the number of iterations goes to infinity [19, 25, 16 and 22]. The exact algorithms give the exact value of the solution in a finite number of loops or iterations [26, 27, 11, 17 and 28].

The present water filling algorithms is more complicated as compared to the simple water filling solutions, regarding the criteria, such as the minimization of the maximum of the BERs of the sub channels or the maximization of the harmonic mean of the SINRs of the sub channels, result in significantly more complicated water filling solutions with multiple water levels and multiple constraints (not just a simple power constraint) [13].

The minimum power design of a MIMO point-to-point communication system that satisfies a set of QoS requirements among the used sub channels also results in a water filling solution with multiple water levels and multiple constraints [29]. In such cases, it is not clear how to compute the numerical solution in practice, not even by adopting an iterative method; however, after a painstaking analysis of the specific structure of each water filling solution, it is still possible to obtain practical algorithms that give the numerical solution [30]. It is thus desirable to develop a general approach to deal with these complicated water filling solutions, as opposed to obtaining results tailored to each particular case.

II. METHODOLOGY

Water filling is a metaphor for the solution of several optimization problems related to channel capacity. The simplest physical example is perhaps the case of spectral

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allocation for maximal total capacity under a total power constraint. Let x_k denote the power received in the kth frequency cell, which has interference (including thermal noise) denoted n_k. If the total received power is constrained to be x, then the total capacity is maximized by solving

$$\max_{\left\{x_k : \sum_k x_k = x\right\}} \sum_k \log(1 + x_k/n_k)$$

$$= \max_{\left\{x_k : \sum_k x_k = x\right\}} \sum_k \log(1 + x_k) - \sum_k \log(n_k)$$

Use Lagrange multipliers and evaluate

$$\frac{\partial}{\partial x_k}\left[\sum_{-j} \log(n_j + x_j) - \mu\left(\sum_j x_j - x\right)\right]$$

to find a solution. The solution satisfies $x_k + n_k = \mu - 1$ for all nonzero x_k. Figure A illustrates the solution graphically as an example of water filling. The difference between the water level (blue) and the noise level (red) is the power allocated to the signal in each frequency cell. The volume of the water is the total received power of the signal. Note that cells with high levels of interference are not used at all. A similar solution results when the capacity is expressed by

$$\sum_k \log(1 + g_k x_k)$$

For gains g_k. One can write the gains as $g_k = n_k - 1$ and use the water-filling argument above. In this context, cells with low gains may not be used at all.

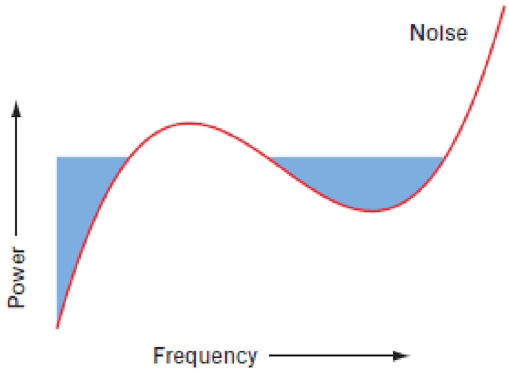

Figure 1. Notional water-filling example.

III. CONCLUSION

In this paper we have considered a theoretical formulation of the maximization of mutual information on each link, subject to power constraints, in the MIMO. Post study of water filling in MIMO systems is contemplated by research papers and review of them structured the literature section of this paper.

Based on uplink-downlink duality, the energy efficiency of the MIMO BC can be transformed into a quasiconcave problem. Based on this feature, we propose an energy efficient iterative water filling scheme to maximize the energy efficiency for the MIMO system.

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