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Adaptive Power Allocation in Mimo Spatial Multiplexing Over Frequency- Selective Rayleigh Fading Channel

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***Abstract*:** In this Paper, we considered MIMO-Spatial Multiplexing with Adaptive Power Allocation and Fixed-Power Allocation for high-speed data transmission over fading channels. We first review results for the Shannon Capacity of fading channels with channel side Information, where capacity is achieved using adaptive transmission techniques. We then derive the spectral efficiency of our proposed modulation. We show that there is a constant power gap between the spectral efficiency of our proposed technique and the channel capacity, and this gap is a simple function of the required Bit-Error Rate (BER). In addition, using just two different signal constellations, we achieve within 1–2dB of the maximum efficiency using unrestricted constellation sets. We compute the rate at which the Transmitter needs to update its power and rate as a function of the channel doppler frequency for these constellation sets. We also obtain the exact efficiency loss for smaller constellation sets, which may be required if the transmitter adaptation rate is constrained by hardware limitations. Our modulation scheme exhibits a 5–10dB power gain relative to variable-power fixed-rate transmission, and up to 20dB of gain relative to non-Adaptive transmission.

Keywords: Multi-Input-Multi-Output (MIMO) System, Adaptive Modulation, Power Allocation, Spectral Efficiency, Spatial Multiplexing and Frequency-Selective Rayleigh Fading Channel.

I. Introduction

In a communication system, two primary resources are employed: transmit power and channel bandwidth is defined as the band of frequencies allocated for transmission of the message signal Haykin (2001). Thus, the general objectives of the system design to maximize the efficiency with which the two resources are used. Recent research has shown that the multiple-input multiple-output (MIMO) architecture is a promising approach to achieve highly efficient wireless communication systems Foschini and Gans (1998). MIMO is a wireless communication technique that uses N_t transmit antennas to transmit messages and the receiver receives the message with N_r receive antennas to improve the link quality and capacity of the system. The capacity of the system increases linearly with the number of antenna elements.

In Goldsmith and Varaiya (1997), various rate and power adaptation schemes are investigated. The power adaptation policy found is essentially a water-filling formula in time. In Goldsmith and Chua (1997), a variable-power variable-rate modulation scheme using M-ary Quadrature Amplitude Modulation (MQAM) is proposed. The presented results show that the proposed technique provides a 5-10dB gain over variable-rate fixed-power modulation using channel inversion and truncated channel inversion (where the received power is maintained constant), and up to 20dB gain over the non-adaptive modulation. In Alouini and Goldsmith (1999), the channel capacity of various adaptive transmission techniques is examined. The performances of these techniques employed with space diversity are also investigated. It is shown that the spectral efficiency for a fading channel can be improved by adaptive transmission techniques in conjunction with space diversity. It is also found that when the transmission rate is varied continuously according to the channel condition, varying the transmit power at the same time has minimal impact.

MIMO technology has much channel capacity by configuring many antennas on the transmitters and receivers compared to traditional SISO channel. Study proves that under the precondition of keeping the channel bandwidth and transmitting power fixed, system capacity is proportional to the smaller of the transmitting antennas number and the receiving antennas number. The other is the obvious spatial diversity. In view of the shortage of bandwidth spectrum nowadays, in order to transmit data with high speed and high capacity, such as in HDTV (High Definition Television) we should have very high spectrum efficiency and the capacity of overcoming the channel fading in the environment of multi-path channel (Ling, 2010). With this transmission scheme, there is a linear increase in spectral efficiency compared to a logarithmic increase in more traditional systems utilizing receive diversity or no diversity (Holter, 2001). The high spectral efficiencies attained by a MIMO system are enabled by the fact that in a rich scattering environment, the signals from each individual transmitter appear highly uncorrelated at each of the receive antennas. When the signals are conveyed through uncorrelated channels between the transmitter and receiver, the signals corresponding to each of the individual transmit antennas have attained different spatial signatures. The receiver can use these differences in spatial signature to simultaneously and at the same frequency separate the signals that originated from different transmit antennas (Holter, 2001).

System Model

1.1 MIMO System

Consider a single user $(n_T\ ;\ n_R)$ MIMO system with n_T transmit and n_T receive antennas as illustrated in Figure 2.1. The system equation is given by

$$r = Hs + n \qquad (2.1)$$

where r is the $n_R \times 1$ received signal vector, s is the complex $n_T \times 1$ transmitted signal vector, n is an $n_R \times 1$ additive white complex Gaussian noise vector, and H is an $n_R \times n_T$ complex channel matrix, which can be represented as

$$\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1nT} \\ h_{21} & h_{22} & \cdots & h_{2nT} \\ \vdots & \vdots & \ddots & \vdots \\ h_{nR1} & h_{nR2} & \cdots & h_{nTnT} \end{bmatrix} \qquad (2.2)$$

The entries, h_{rs}, r = 1,2, ..., n_R *and* s = 1,2,..., n_T of **H** are the channel coefficients between receive antenna r and transmit antenna s.

$$h_{rs} = A_{rs} \exp(j\theta_{rs}) \qquad (2.3)$$

where θ_{rs} are independent and identically distributed (i.i.d.) uniform phase variables over $[0,\ 2\pi]$ and the A_{rs} are i.i.d. amplitudes drawn from a range of distribution types. As is standard practice, we normalize the amplitude distributions so that the mean power is unity, $E[A^2rs]$= 1. This allows a fair comparison across distribution types.

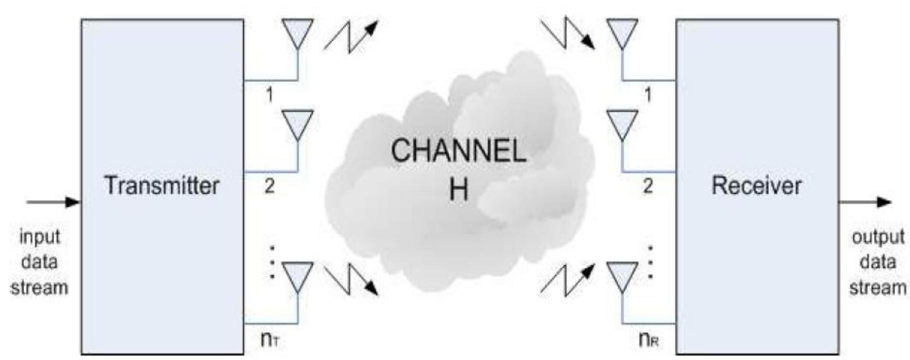

Figure 2.1: A MIMO system model

1.2 Adaptive Modulation MIMO System

In the adaptive modulation scheme the channel is estimated in the receiver and fed back to the transmitter. The transmitter adapts the transmitting signal considering the feedback information to maximize the spectral efficiency. We assume that the feedback path dose not introduce any errors and delay. The availability of channel information at the transmitter allows it to adapt its transmission power and rate relative to the channel variation Chung and Goldsmith (2001). A variable-rate variable-power (VRVP) adaptation scheme is considered here. According to the above decomposition, the adaptive modulation MIMO problem may be considered as an adaptive modulation SISO problem using the unordered eigenvalue distribution Zhou et al (2005). Hence, the following problem should be solved by maximizing the average spectral efficiency (ASE):

$$\text{ASE} = m\sum_{j=1}^{N} SE_j \left[\Psi_1\left(1, v_j\right) - \Psi_1\left(1, v_{j+1}\right)\right] \qquad (2.4)$$

II. Methodology

The adaptive modulator and demodulator are executed in software (MATLAB). For a given data stream, MATLAB builds up a frame by using a desired transmission scheme. After signal transmission over test-bed, the received frames are sent to MATLAB to be processed. Local area network (LAN) is used to close the feedback path. Almost all the required processing is done in MATLAB in both the transmitter and receiver. In the receiver, matched filtering, timing recovery, frame detection, channel estimation, frequency offset estimation, carrier phase tracking, MIMO detection and adaptive demodulation are done in MATLAB. Adaptive modulation and pulse shaping are done in MATLAB transmitter. In addition, a channel simulator is implemented in MATLAB and is placed after MIMO transmitter. Three signal generators with very low phase noise are used as the local oscillators. In all measurements, the symbol rate is 125kbps, the frame length is 1024 symbols, the training sequence length is 128 symbols and the frame detection preamble length is 32 symbols. A root-raised-cosine filter with roll-off 0.3 is used for pulse shaping. Also implementation loss has been estimated by SISO AWGN measurement and the system has been calibrated considering this estimated implementation loss. The measurement results of adaptive modulation MIMO system are presented for a set of average SNRs. For each SNR, 2000 frames are transmitted and the results are averaged. $Nr = Nt = 4$ and $k_1(\varkappa_1) \in \{0,2,4,6,8\}$. Rayleigh fading channel is used in channel simulator. The BER_{tgt} = 0.01 is selected for our measurements.

Table 3.1 MATLAB Simulation Parameters

Parameters	Values
MIMO Antenna Configuration	$2 \times 2, 3 \times 3, 4 \times 4$
Signal- Noise- Ratio (SNR)	0-25dB
Modulation	(4, 8, 16 and 64)-QAM
BER Threshold	10^{-2}
Signal Bandwidth	2MHz
Mobile Speed	30km/hr
Carrier Frequency	900MHz
Channel	Frequency-Selective Rayleigh Fading Channel
Number of Multipath	3
Filter	Square root raised cosine

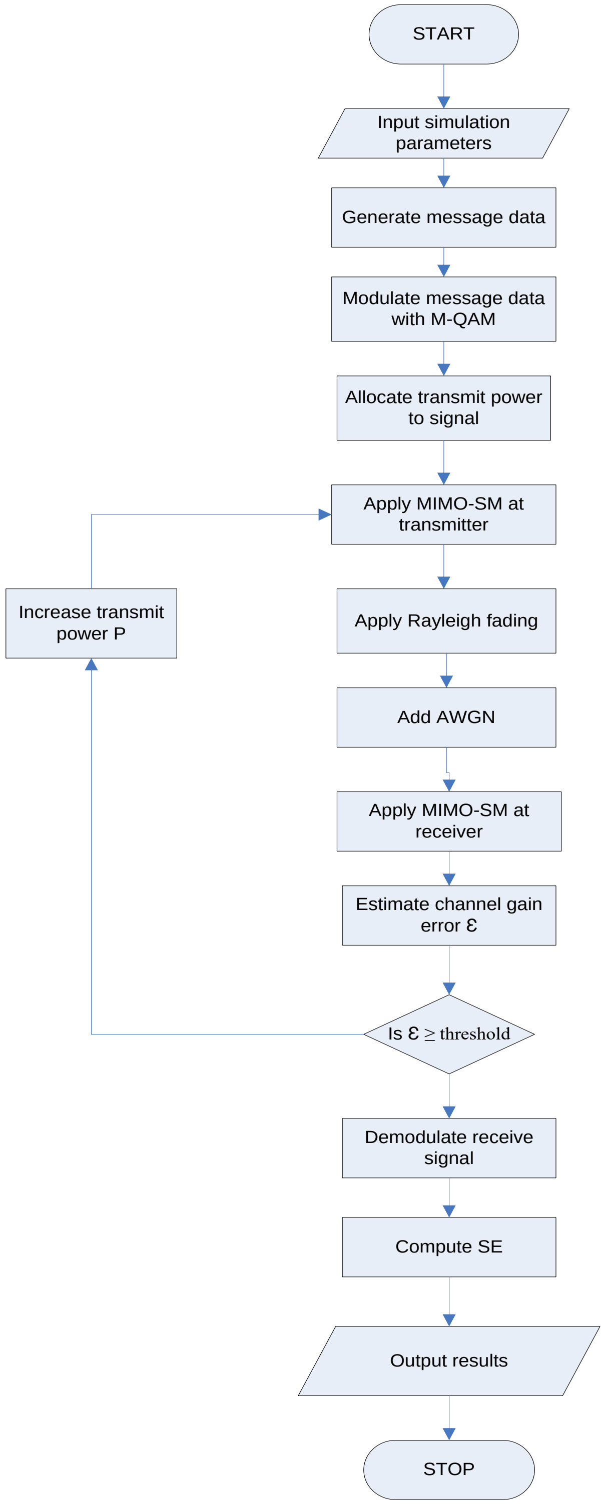

Figure: 3.1 System Simulation Flow-chart

III. Results And Discussion

Results
The simulation results are given as follows:

The table below shows the results of Signal-Noise-Ratio (SNR) at decibels up 25dB for both adaptive power allocation and fixed power allocation a 2×2 MIMO Antenna.

Spectral Efficiency of 2×2 MIMO (threshold of $\mathbf{10^{-2}}$)		
SNR [dB]	Adaptive power allocation	Fixed power allocation
0	2.7541	0.0450
1	2.8747	0.3654
2	3.1692	0.5338
3	3.2878	0.7043
4	3.6213	0.7980
5	3.9423	0.9520
6	4.2602	1.0721
7	4.3792	1.2874
8	4.5978	1.5880
9	4.6434	1.9621
10	4.7409	2.3685
11	4.7431	2.8312
12	4.8688	3.3486
13	5.0725	3.7883
14	5.5317	4.1526
15	6.1184	4.5478
16	6.5982	4.8440
17	6.9843	5.0680
18	7.0590	5.1871
19	7.2079	5.4311
20	7.4015	5.4695
21	7.5303	5.6544
22	7.7115	5.9320
23	7.8941	6.5033
24	7.9446	7.0384
25	8.0251	8.0505

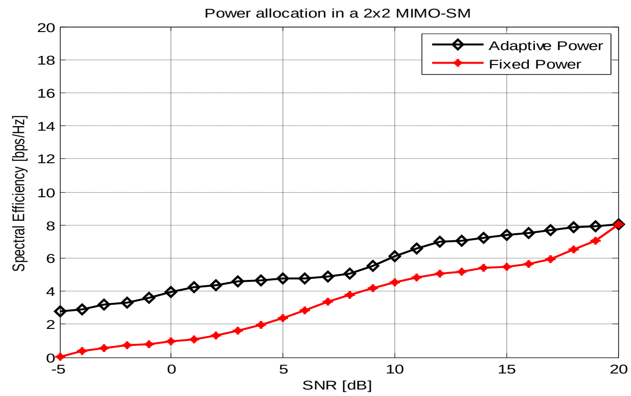

Figure 4.1: Simulation graph showing the spectral efficiency of a 2×2 MIMO Antenna.

The table below shows the results of Signal-Noise-Ratio (SNR) at decibels up 25dB for both adaptive power allocation and fixed power allocation a 3×3 MIMO Antenna.

Spectral Efficiency of 3×3 MIMO (threshold of $\mathbf{10^{-2}}$)		
SNR [dB]	Adaptive Power Allocation	Fixed Power Allocation
0	4.0810	0.0386
1	4.1126	0.1795
2	4.1747	0.2642
3	4.2315	0.3308
4	4.4106	0.4547
5	4.7259	0.5092
6	5.0070	0.6192
7	5.7222	0.7526
8	5.7459	1.0684
9	6.1888	1.4137
10	7.0519	1.8770
11	7.3326	2.4413
12	8.1004	3.1217
13	9.0253	3.6955
14	9.3538	4.2006
15	9.5008	4.7172
16	10.4915	5.2158
17	11.5498	5.7566
18	12.1256	6.3384
19	12.2674	7.0746

20	12.5113	7.8405
21	12.9469	8.5308
22	12.9692	9.1408
23	13.2214	9.6645
24	13.6628	10.0892
25	15.1549	10.3468

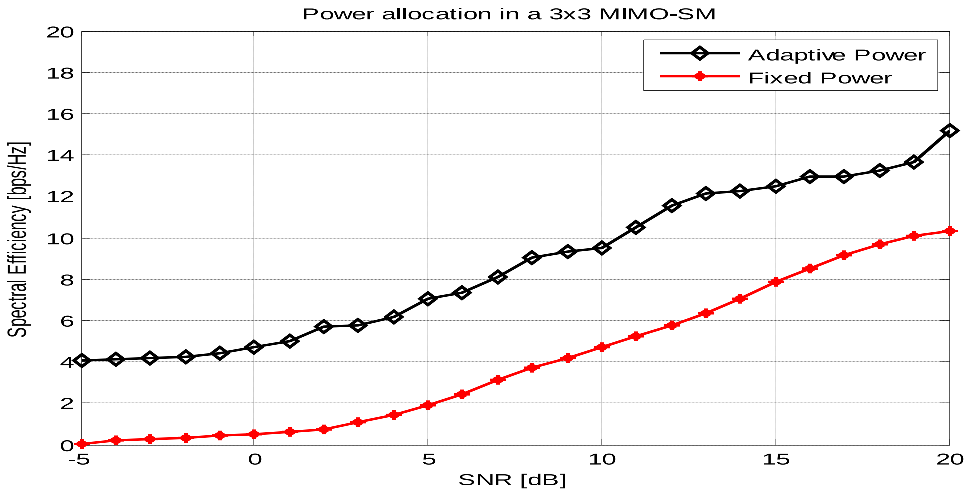

Figure 4.2: Simulation graph showing spectral efficiency 3× 3 MIMO Antenna.

The table below shows the results of Signal-Noise-Ratio (SNR) at decibels up 25dB for both adaptive power allocation and fixed power allocation a 4 × 4 MIMO Antenna.

Spectral Efficiency of 4 × 4 MIMO (threshold of $\mathbf{10^{-2}}$)		
SNR [dB]	Adaptive Power Allocation	Fixed Power Allocation
0	4.2214	0.0578
1	4.5139	0.2000
2	4.5455	0.3081
3	4.8830	0.4625
4	5.2918	0.6337
5	5.7291	0.8775
6	6.1651	1.2005
7	7.0557	1.6274
8	7.8208	1.9838
9	7.8893	2.3860
10	8.5411	2.8027
11	9.4349	3.1157
12	10.3094	3.4546
13	10.3745	3.9759
14	11.0981	4.5318
15	11.5915	5.1371
16	12.2986	5.9303
17	12.9691	6.7821

18	13.2976	7.5793
19	13.4898	8.3653
20	14.1710	8.9951
21	14.7447	9.5548
22	15.0018	9.9757
23	15.2483	10.6321
24	16.0384	11.1880
25	16.5846	12.4862

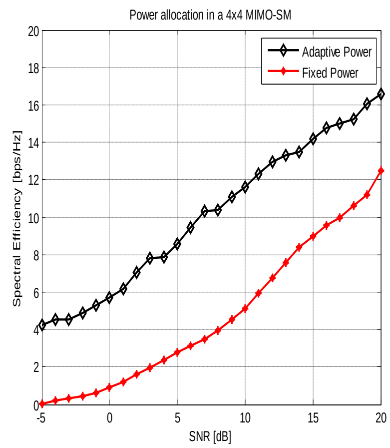

Figure 4.3: Simulation graph showing the spectral efficiency of a 4×4 MIMO Antenna.

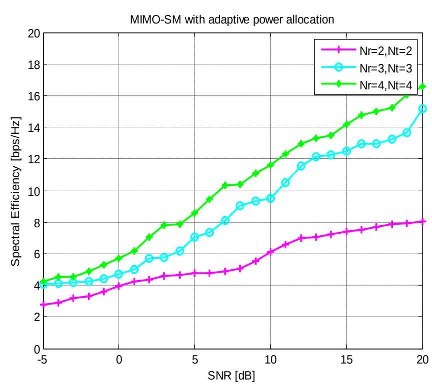

Figure 4.4: Comparison between various antenna configurations using MIMO-SM with adaptive power allocation. Target BER $= 1 \times 10^{-2}$

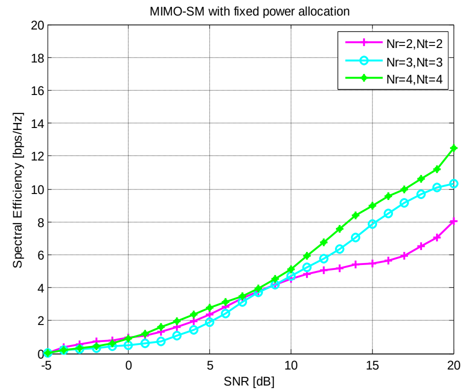

Figure 4.5: Comparison between various antenna configurations using MIMO-SM with fixed power allocation. Target BER $= 1 \times 10^{-2}$.

IV. Discussion

The results show the spectral efficiency that can be achieved by MIMO systems of different configurations. From the results we observed that power can be allocated to channel using both adaptive power allocation and fixed power allocation. The comparison of different MIMO Antenna Configurations show that the 4×4 configuration will give higher and better spectral efficiency than the other configurations. Furthermore, the comparison between adaptive power allocation and fixed (non-adaptive) power allocation, the adaptive power allocation gives high and better spectral efficiency at high SNR than the fixed power allocation method. So therefore, the higher the SNR the lower BER.

Power (resource) allocation can be used to maximize the number of bits (spectral) transmitted by varying the transmit power of each channel in an adaptive MIMO system while maintaining the system BER below the target BER. In other words, it maximizes the throughput under power and QoS constraints. Power allocation is used to give the excess power to a weaker link or other links that require extra power to switch to higher modulation modes to improve the efficiency of the system. In power allocation, transmit power is dynamically allocated in each channel. Finally, we can infer from figure 4.4 and 4.5 showing the graphical simulation results of the three antennas i.e. 2×2, 3×3 and 4×4 MIMO-SM antennas were compared. Taking 20dB SNR as the point of comparison, the spectral efficiency of a 4×4 MIMO Antenna with adaptive power allocation has the highest spectral efficiency than the one of fixed power allocation.

V. Conclusion

We have proposed an adaptive and fixed-power MQAM modulation technique which adapts to the channel variation. We compare the spectral efficiency of our adaptive method to the theoretical bound on spectral efficiency, and to the efficiency of suboptimal and nonadaptive modulation techniques. We first show that there is a constant gap between the channel capacity and the maximum efficiency of adaptive MQAM which is a simple function of the target BER. We also show that, using just two different signal constellations, we get a spectral efficiency within 1 dB of the efficiency without constellation restriction. Moreover, our adaptive technique has a 5–10 dB power gain over variable power fixed-rate modulation, and up to 20 dB of power gain over non-adaptive modulation. Our technique is sensitive to channel estimation errors and to estimation and feedback path delay, and this must be taken into account in any practical implementation. We also determine how fast the transmitter must change its constellation and power as a function of the channel Doppler frequency. Hardware constraints will dictate whether these adaptation rates are feasible. In the final section, we discuss coding techniques, and reflect on the connection between the Shannon capacity of our channel model and the adaptive MQAM technique we propose.

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