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PARISMITA A. KASHYAP

Department of Electronics & Communication Engineering, Tezpur University, Tezpur – 784028, Assam, India, parismita3@gmail.com

Kandarpa Kumar Sarma

Department of Electronics and Communication Technology, Gauhati University, Guwahati, Assam-781014, kandarpaks@gmail.com

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SELF ADAPTIVE EFFECTIVE APERTURE FOR MULTI ANTENNA SET-UPS IN FADED WIRELESS CHANNELS

PARISMITA A. KASHYAP¹, KANDARPA KUMAR SARMA²

¹Department of Electronics & Communication Engineering, Tezpur University, Tezpur – 784028, Assam, India

²Department of Electronics and Communication Technology, Gauhati University, Guwahati – 781014, Assam, India

E-mail: parismiak3@gmail.com, kandarpaks@gmail.com

Abstract- In mobile communication, a less explored technique to mitigate fading effects is based on the physical parameter of the transmitter by varying the physical dimension of the transmitting antenna. This paper deals with a self adaptive system to eliminate severe fading effects in different multi antenna set-ups by adaptively updating the effective aperture of the transmitting antenna. The system changes the effective aperture of the transmitting antenna to adapt to a previously set system parameter. We consider here Single input-single output (SISO), Single input-multi output (SIMO), Multi input-single output (MISO), and Multi input-multi output (MIMO) system with three different modulation schemes - BPSK, DPSK and QAM. Finally, the system performance is analyzed for the different set-ups in terms of Bit error rate (BER). We will see that our results show significantly better performance.

Keywords- Rayleigh slow flat fading; Rayleigh slow frequency selective fading; Hamming codes; Effective Aperture; Least Mean Square (LMS)

I. INTRODUCTION

Mobile communication has achieved a high success rate over the past decades. The mobile radio channel however, poses a severe challenge as a medium for reliable high speed communication. The presence of static as well as mobile obstacles in the channel creates multiple paths that the transmitted signal can traverse. As a result, the receiver sees the superposition of multiple copies of the transmitted signal, each traversing a different path which can either lead to constructive or destructive interference. Strong destructive interference is often referred to as a deep fade and may result in temporary failure of communication due to a severe drop in the channel signal-to-noise ratio (SNR) [1].

So, to eliminate such deep fades a self adaptive system for multi antenna set-ups is designed where the desired Bit error rate (BER) is predefined as a threshold. We assume that the receiver has no knowledge of the Channel state information (CSI). Hence, for the different multi antenna set-ups an estimate of the different channel matrices are made using the LMS algorithm. Depending upon the performance recorded, the effective aperture of the transmitting antenna which is related to its physical dimension is adaptively raised in uniform steps until the threshold BER is obtained.

We first analyze our technique for a Single input-single output (SISO) set-up. The data stream is first encoded using hamming codes and then modulated using BPSK modulation, after which it is transmitted along with the transmitter gain through Rayleigh fading channels. The transmitter gain is related to the effective aperture of the transmitting antenna and

hence varying the effective aperture causes the transmitter gain to vary. We consider a Rayleigh flat fading (FF) channel and a Rayleigh frequency selective fading (FSF) channel, and transmit our data stream first through the FF channel and then through the FSF channel. Both the channels are slow fading channels. At the receiver, equalization of the received stream is performed and it is demodulated and decoded to obtain the original data stream. Finally, average BER is calculated and the system checks whether the BER is equal to the threshold value. If not, the system automatically increases the effective aperture of the transmitting antenna to improve the BER performance. When the threshold value is reached, the effective aperture is no further increased and that the BER obtained is the final desired BER required for successful reception of the transmitted data. This simple technique is then expanded to different multi antenna set-ups where we consider a 1×2 SIMO, a 2×1 MISO, and a 2×2 MIMO system. We also perform the same for DPSK and QAM modulations as well. Expected results are obtained for all the cases and the performances are compared. The rest of the paper is organized as follows:

In Section II, brief discussions on the related theoretical considerations are included. In Section III, the system model is shown and explained. Results and Discussions are included in Section IV and Section V concludes the work.

II. THEORETICAL BACKGROUND

Here, we briefly describe the theoretical considerations related to the work.

A. Slow Flat fading

If a mobile radio channel has a constant gain and linear phase response over a bandwidth which is

greater than the bandwidth of the transmitted signal, and the channel impulse response changes at a slower rate than that of the transmitted signal, then the received signal will undergo slow FF.

If the channel induces amplitude which varies in time according to the Rayleigh distribution, then the channel is assumed to be a Rayleigh flat fading channel model [2].

Thus, a signal undergoes slow FF if

$$B_D \ll B_S \ll B_C \quad (1)$$

And $T_C \gg T_S \gg \sigma_\tau$

$$(2)$$

where T_S is the reciprocal bandwidth and B_S is the band width respectively of the transmitted modulation, and σ_τ and B_C are the rms delay spread and coherence bandwidth, respectively, of the channel.

Figure 1: Block diagram of the overall set-up

B. Slow Frequency Selective fading

If the channel possesses a constant-gain and linear phase response over a bandwidth that is smaller than the bandwidth of the transmitted signal, and the channel impulse response changes at a slower rate than that of the transmitted signal, then the channel creates slow FSF on the received signal. If such a channel model varies according to the Rayleigh distribution it is called a Rayleigh frequency selective channel model [2].

$$B_S > \tilde{B}_C \quad (3)$$

$$B_S > B_D \quad (4)$$

$$\text{and } T_S < T_C \quad (5)$$

$$T_S < \sigma_\tau \quad (6)$$

where the symbols have their usual meanings.

C.]Hamming codes

Hamming codes are a subclass of linear block codes that are expressed as a function of a single integer, $m \geq 2$. Here the codeword length is given by $n = 2^m - 1$, number of information bits is given by $k = n - m$, number of parity bits is $n - k = m$. The columns of the parity check matrix, B consists of all non-zero binary m -tuples [3].

D. Effective Aperture (A_e)

The effective aperture, A_e is related to the physical size of an antenna. It may often be very much larger than the physical area, especially in case of wire antennas. However, the effective aperture will reduce

as the efficiency of an antenna decreases. This is related to the gain, G of the transmitter antenna as follows [4]

$$A_e = \frac{G\lambda^2}{4\pi} \quad (7)$$

E. Least Mean Square (LMS) Algorithm

LMS is the simplest algorithm used for adaptive processing, based on the steepest-descent method which recursively computes and updates the weight vector [5].

$$y(n) = w^H x(n) \quad (8)$$

$$e(n) = d(n) - y(n) \quad (9)$$

$$w(n+1) = w(n) + \mu x(n)e^*(n) \quad (10)$$

where, $w(n)$ is the input to the adaptive filter, $y(n)$ is the signal at the output of the filter, $d(n)$ is the desired signal, $e(n)$ is the error signal, w^H is the weight vector and μ is the step size.

III. SYSTEM MODEL

The system block diagram is shown in Fig. 1 which depicts the overall set-up of the model. It consists of the encoder, the modulator, the transmitter, the receiver, the demodulator, the decoder and the fading channel. The effective aperture is adaptively varied until BER performance reaches the threshold. We consider two channel models for this-FF channel and FSF channel for a practical GSM system. The values considered for the different channel modeling parameters are shown in Table 1.

The behavior of the block diagram (Fig 1.) when realized for different multi antenna set-ups takes a form as described in the sections below:

A. SISO Set-up

The system model for a SISO environment simply consists of a transmitter and a receiver with a single transmitting and receiving antenna. We consider a practical GSM system, where we assume that the transmitter is static, but the receiver is mobile.

The data stream say S , after passing through the transmitter block goes through the channel to the receiver block. The transmitter block consists of an encoder and a modulator where the data is first encoded using hamming (15,11) codes and then modulated using BPSK scheme. After modulation the data is aided with the transmitter gain and then transmitted through a Rayleigh fading channel where it is subjected to noise and other channel impairments. The transmitted data is

$$X_T = GS \quad (11)$$

where G is the transmitter gain. This transmitter gain, G is related to the effective aperture of the antenna as (7). Thus, as the effective aperture changes, there is a variation in the transmitting antenna gain.

We consider here, two states for the Rayleigh fading channel as discussed below.

1) Flat fading channel model

The receiver is assumed to be a moving vehicle in a suburban environment with a velocity, v . The rms delay spread of the channel is σ_τ (values are shown in Table 1.) The bandwidth, B_s of the transmitted modulation is assumed to be 100KHz. The maximum Doppler shift, f_m is given by

$$f_m = \frac{vf_c}{c} \quad (12)$$

where v is the velocity in m/s, f_c is the carrier frequency in Hz and c is the speed of light in m/s

Again the coherence time, T_c is given by

$$T_c = \frac{9}{16\pi f_m} \quad (13)$$

and the coherence bandwidth, B_c is given by

$$B_c = \frac{1}{5\sigma_\tau} \quad (14)$$

We model the channel using the above parameters and find the coherence bandwidth B_c , to be greater than the transmitted signal bandwidth, B_s . Thus, the channel induces FF.

2) Frequency selective fading channel model

Here, for the same GSM system, we assume that the receiver is a vehicle moving with a velocity, v in an

urban environment. Considering (12), (13) and (14), we model the channel and find that B_c is less than B_s . B_s in this case too is 100KHz. Thus the channel induces FSF.

Due to the effect of noise, v and the channel H , the received data at the receiver becomes

$$Y_R = HX_T + v \quad (15)$$

The channel matrix, H is totally unknown to the receiver. So, by applying the LMS algorithm an estimate of H is obtained as discussed below-

The received signal at the receiver input is the input to the adaptive filter and the reference signal (desired) is the delayed version of the received signal. The weights are updated using (10). So, in this case using (8) and (9)

Figure 2. Adaptive filter

$$\hat{Y} = w(n)Y_R(n), \quad (16)$$

$$e(n) = Y_R(n-1) \square Y_R(n). \quad (17)$$

When $e(n) \rightarrow 0$

$$\hat{Y}_R = Y_R(n-1) \quad (18)$$

Therefore,

$$\hat{H} = \frac{\hat{Y}_R}{X_T(n-1)} \quad (19)$$

$\hat{H}$ contains noise, v . So, it has to be removed from $\hat{H}$. Finally, the actual estimated $\hat{h}$ is obtained by subtracting the noise from $\hat{H}$

$$\hat{h} = \hat{H} \square v \quad (20)$$

Thus, the recovered data at the receiver output is

$$Y = \frac{Y_R}{\hat{h}} \quad (21)$$

$$Y = \frac{hX_T + v}{\hat{h}} \quad (22)$$

$$Y = X_T + \tilde{v} \quad (23)$$

where $\tilde{v} = \frac{v}{h}$ is the additive noise scaled by the channel coefficient.

The recovered data stream is then demodulated and decoded to get the original transmitted data stream. For both FF and FSF channels, effective aperture of the transmitting antenna is increased until the desired BER in the range of 0.0006 with a tolerance of $\pm 50\%$ is obtained.

B. SIMO Set-up

The system model for a SIMO set-up has one transmitting and two receiving antennas. The two

receivers are assumed to be mobile and the transmitter is static.

The single data stream is transmitted in a similar fashion as in the SISO case given by (11). This data is received by both the receiving antennas through two different paths. The channel models for the two separate paths are discussed below.

1) Flat fading channel model

Here, since both the receivers are mobile, we consider both of them to be a moving vehicle in a suburban environment, with two different velocities, v_1 and v_2 . The rms delay spread of the first and second channel are also different. The bandwidth, B_s is similar to the SISO case. Taking (12), (13) and (14) into consideration and modelling the channel with the above parameters, we find B_{C1} and B_{C2} to be less than B_s . Thus, the channel is a FF channel.

2) Frequency selective fading channel model

Here, we consider the two receivers to be vehicles moving with a velocity, v_1 and v_2 in an urban environment. Both the channels have different rms delay spreads, $\sigma_{\tau 1}$ and $\sigma_{\tau 2}$. The rest of the considerations are similar to that of the FF channel case and we calculate B_{C1} and B_{C2} and found that the channel is frequency selective.

The received streams at both the receiving antennas due to the effect of fading are given by-

$$Y_{R1} = H_1 X_T + v \quad (24)$$

$$Y_{R2} = H_2 X_T + v \quad (25)$$

So, the first objective here will be to determine the channel matrices for both these paths. Estimate of the channel matrices are done separately at both the receiving antennas as discussed in the SISO case and equalization is performed. Thus, the recovered data streams are-

$$Y_1 = \frac{Y_{R1}}{\hat{h}_1} \quad (26)$$

$$Y_1 = \frac{\hat{h}_1 X_T + v}{\hat{h}_1} \quad (27)$$

$$Y_1 = X_T + \square_1 \quad (28)$$

$$Y_2 = \frac{Y_{R2}}{\hat{h}_2} \quad (29)$$

$$Y_2 = \frac{\hat{h}_2 X_T + v}{\hat{h}_2} \quad (30)$$

$$Y_2 = X_T + \square_2 \quad (31)$$

where $\square_1 = \frac{v}{\hat{h}_1}$ and $\square_2 = \frac{v}{\hat{h}_2}$ is the additive noise scaled by the first and second channel coefficients respectively.

After demodulating and decoding the data, it is successfully recovered at the output. Effective aperture is dynamically varied until mean BER of 0.0004 with a $\pm 50\%$ tolerance is achieved.

C. MISO Set-up

The system model for a MISO set-up has two transmitting and one receiving antenna. The receiver is mobile just like the previous cases.

Here, two separate data streams after modulation are transmitted from the two transmitting antennas together with the transmitter gain.

$$X_{T1} = G_1 S_1, \quad (32)$$

$$X_{T2} = G_2 S_2, \quad (33)$$

where G_1 and G_2 are the gains at the first and second transmitting antennas respectively. These two transmitter gains are related to the effective aperture of the antennas as in (7).

These data streams are first passed through both the Rayleigh fading channels. The two channel models are described below.

1) Flat fading channel model

In this case we proceed in a similar fashion as the SISO case, except that there are two transmitted messages with two different carrier frequencies. The bandwidth of both these transmitted messages is 100KHz. For the same suburban environment we consider the receiver to be a vehicle moving with a velocity, v . Since there are two transmitted data streams, it reaches the receiver through two separate faded paths having different rms delay spreads. After modeling the channel using (12), (13) and (14), we found the coherence bandwidth for both the paths to be greater than the bandwidth of the transmitted signal.

2) Frequency selective fading channel model

Here, the only difference in the channel model with that of the FF model is in the receiver velocity, the rms delay spread of the channel, and that the environment is urban. After modeling the channel we found it to be frequency selective.

These two data streams arrive at the receiving antenna through two different paths as

$$Y_R = H_1 X_{T1} + H_2 X_{T2} + v \quad (34)$$

At the receiver, an estimate of the delayed version of the received stream is made using (8), (9), and (10). Proceeding in the same manner as the SISO case and using (16), (17) and (18), we determine the channel matrices H_1 and H_2 . Thus

$$\hat{H}_1 = \frac{\hat{Y}_R - H_2 X_{T2}}{X_{T1(n-1)}} \quad (35)$$

$$\hat{H}_2 = \frac{\hat{Y}_R - H_1 X_{T1}}{X_{T2(n-1)}} \quad (36)$$

Noiseless channel matrices are given by-

$$\hat{h}_1 = \hat{H}_1 - v \quad (37)$$

$$\hat{h}_2 = \hat{H}_2 - v \quad (38)$$

The two data streams are recovered as shown below-

$$Y_1 = \frac{h_1 X_{T1} + v}{h_1} \quad (39)$$

$$Y_1 = X_{T1} + \square_1 \quad (40)$$

$$Y_2 = \frac{h_2 X_{T2} + v}{h_2} \quad (41)$$

$$Y_2 = X_{T2} + \square_2 \quad (42)$$

Since we receive two copies of the data at the output, in our case, both the results are combined to get a single output, Y . This may alter as per the requirement of the system. Until a BER value in the range of 0.0002 with a tolerance of $\pm 50\%$ is attained, the effective aperture of the transmitting antenna is adaptively raised for both FF and FSF channels.

D. MIMO Set-up

A MIMO set-up has two transmitting and two receiving antennas. The transmitter side is similar to the MISO case, where two separate data streams are transmitted along with the transmitter gain. But the receiver side is somewhat different. Each of the receiving antennas receives both the transmitted data streams which are distorted due to the channel and noise.

The data arrive at the receiving antennas through four different paths and hence at both the receivers, the primary objective is to determine the four channel matrices.

This is done in a similar way as the MISO case at both the receiving sides. The transmitted streams are given by (32) and (33). The two channel models are discussed below.

1) Flat fading channel model

As the transmitted data streams arrive at the receivers through four different faded paths, we model the four paths taking the parameters in Table 1. After modeling the channel in a similar way as that of the above discussed cases, we find the coherence bandwidth of all the four paths to be greater than the transmitted message bandwidth and hence the channel induces FF.

2) Frequency selective fading channel model

Here, for the same urban situation the parameters (Table 1.) are calculated in a similar fashion as the other set-ups and we find that the channel induces FSF.

Thus, the received streams at the first and the second receiving antennas are

$$Y_{R1} = H_1 X_{T1} + H_2 X_{T2} + v \quad (43)$$

$$Y_{R2} = H_3 X_{T1} + H_4 X_{T2} + v \quad (44)$$

At the receiver, equalization is performed separately for both the received streams in the same way as the MISO case. Thus, the final outputs are

$$Y_1 = X_{T1} + \square_1 \quad (45)$$

$$Y_2 = X_{T2} + \square_2 \quad (46)$$

$$Y_3 = X_{T1} + \square_3 \quad (47)$$

$$Y_4 = X_{T2} + \square_4 \quad (48)$$

Y_1 and Y_2 are combined to get the first received stream, Y_{F1} and Y_3 and Y_4 are combined to get the second received stream, Y_{F2} . Demodulation and decoding is finally done to recover the original data streams. BER is obtained for Y_1 , Y_2 , Y_3 and Y_4 separately and an average is taken both for flat and frequency selective fading. Effective aperture is raised until BER of 0.0002 with a $\pm 50\%$ tolerance is obtained.

TABLE 1. SIMULATION PARAMETERS CONSIDERED FOR CHANNEL MODELING

Parameter	SISO	SIMO	MISO	MIMO
Carrier frequency	fc=1.5GHz	fc=1.5GHz	fc1=1.5GHz, fc2=1.9GHz	fc1=1.5GHz, fc2=1.9GHz
Velocity (FF)	v=100km/hr	v1=100km/hr, v2=110km/hr	v=110km/hr	v1=110km/hr, v2=90km/hr
Velocity (FSF)	v=120km/hr	v1=120km/hr, v2=105km/hr	v=120km/hr	v1=120km/hr, v2=110km/hr
RMS delay spread (FF)	σ =245ns	σ 1=245ns, σ 2=255ns	σ 1=245ns, σ 2=240ns	σ 1=245ns, σ 2=240ns, σ 3=260ns, σ 4=250ns
RMS delay spread (FSF)	σ =24 μ s	σ 1=24 μ s, σ 2=25 μ s	σ 1=24 μ s, σ 2=25 μ s	σ 1=24 μ s, σ 2=25 μ s, σ 3=24 μ s, σ 4=23 μ s

IV. RESULTS AND DISCUSSIONS

The different multi antenna set-ups discussed in Section III are coded and simulated using MATLAB. The simulation parameters considered for simulation are given in Table 2.

Fig. 3 shows the Ae vs BER curve for all the multi antenna set-ups both for FF and FSF using BPSK modulation.

Here, the first plot (Fig. 3A) is for the Ae vs. BER curve for a SISO system for both FF and FSF. We see that, with an increase in the effective aperture of the transmitting antenna, BER performance goes on improving to reach the desired BER level. Similar results can be seen for the SIMO (Fig. 3B), MISO (Fig. 3C) and MIMO (Fig. 3D) systems. In this case, the SNR is kept fixed at 2dB. In the MISO and MIMO systems, since there are two transmitting antennas, the apertures of both the antennas are simultaneously raised. However, in Fig. 3C and 3D, the x-axis values indicated are only for one antenna although the other antenna aperture is also raised simultaneously together with the first one in similar increments.

TABLE 2. SIMULATION PARAMETER CONSIDERED FOR SIMULATION

Parameter	Value/Type
-----------	------------

Bandwidth of transmitted signal	100KHz
Carrier modulation used	BPSK, DPSK, QAM
Channel used	Rayleigh flat fading, Rayleigh frequency selective fading
Coding technique used	Hamming (15,11)
BER threshold set	0.0006±50% for SISO, 0.0004±50% for SIMO, 0.0002±50% for MISO and 0.0002±50% for MIMO.

DPSK modulation makes the BER performance unsatisfactory.

Figure 5. A_e vs. BER curve for flat and frequency selective fading for SISO and SIMO set-ups using DPSK modulation

Figure 3. A_e vs. BER curve for FF and FSF for all the multi antenna set-ups using BPSK modulation

Fig. 4 shows the A_e vs BER curves for both FF and FSF in all the multi antenna set-ups using QAM modulation.

Figure 3. A_e vs. BER curve for FF and FSF for all the multi antenna set-ups using BPSK modulation

From Fig. 4 we see that the performance of all the set-ups is satisfactory for both FF and FSF. Here, too the SNR is kept fixed at 2dB. Fig. 9A and 9B shows the BER curves for SISO and SIMO respectively in both flat and frequency-selective fading channels using DPSK modulation. From the curves it is clear that there is a significant improvement in the BER performance of the systems with increase in effective aperture.

Here we are not showing the BER curves for MISO and MIMO systems as these systems does not work satisfactorily with the proposed technique. This is perhaps due to the computational complexity involved in these systems when employing DPSK modulation. Also, the increased error probability of

TABLE 3. PERFORMANCE OUTPUT TABLE

Set-ups		Final BER obtained as per threshold set			A _e range obtained to reach threshold in sq. m		
		BPSK	QAM	DPSK	BPSK	QAM	DPSK
SISO	FF	0.00064	0.00047	0.00050	0.001 to 0.010	0.001 to 0.012	0.001 to 0.011
	FSF	0.00066	0.00087	0.00064	0.001 to 0.010	0.001 to 0.011	0.001 to 0.010
SIMO	FF	0.00049	0.00037	0.00043	0.001 to 0.011	0.001 to 0.012	0.001 to 0.011
	FSF	0.00047	0.00058	0.00060	0.001 to 0.011	0.001 to 0.011	0.001 to 0.010
MISO	FF	0.00024	0.00011	0.2680	0.001 to 0.006	0.001 to 0.006	□
	FSF	0.00018	0.00022	0.2784	0.001 to 0.006	0.001 to 0.006	□
MIMO	FF	0.00018	0.00020	0.2753	0.001 to 0.006	0.001 to 0.006	□
	FSF	0.00027	0.00023	0.2788	0.001 to 0.007	0.001 to 0.006	□

Table 3. shows the performance output which gives a clear picture of the work and the results obtained. From the table, the final BER values and the effective aperture range obtained after the threshold is reached for all the modulation schemes used can be seen. The BER values are within the threshold limit (given in Table 2.) with a ±50% tolerance. Also, from the A_e range we find that, on an average with BPSK modulation, our system performs better compared to QAM and DPSK modulations. Moreover, BPSK being a coherent scheme, the feedback path (Fig. 1) from the output of the system to the transmitter is significantly contributing to the improvement of the system. We, also see from Table 3. that the BER performances of the MISO and MIMO set-ups with DPSK modulation is totally unsatisfactory. So, the effective aperture range required for successful reception of the transmitted data and stable operation of the system cannot be determined.

V. CONCLUSION

In this paper, a self adaptive effective aperture based multi antenna system is tested. The proposed scheme has been verified in Rayleigh flat and Rayleigh frequency-selective fading channels for BPSK, DPSK and QAM modulation. It has been observed that to attain the BER required for reliable recovery of the original information transmitted, effective aperture of the transmitting antenna can be adaptively updated.

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