Performance Study of Diversity Combining Techniques for Error-floor Reduction in Fast Fading Channels

Yazid Khattabi[1], Haythem Bany Salameh[2], and Mohammad Al-Ibrahim[3]
[1]King Abdullah II Design & Development Bureau,
[2]Telecommunications Engineering Department, Yarmouk University
[3]Electrical Engineering Department, Jordan University Of Sciecnce & Tech.,
Irbid, Jordan
ykhattabi@kaddb.mil.jo, haythem@ece.arizona.edu, ibrahim@just.edu.jo

Abstract: - We investigates the effect of mobile speed, channel estimation rate, diversity order on performance degradation due to error floor in a mobile Single-Input-Multiple-Output (SIMO) wireless communication system. Each diversity channel is assumed to be fast Rayleigh fading process, which is modeled as a first order autoregressive process. Diversity channels are assumed to be independent and identically distributed (i.i.d) with identical channel correlation parameters and channel estimation rates at each receiving antenna. Two receiving diversity combining techniques are used: maximum ratio combining (MRC) and selection combining (SC), and two binary modulation schemes are considered: coherent PSK (BPSK) and differentially coherent PSK (BDPSK). The performance is investigated in terms of the overall average output received signal-to-noise-ratio (SNR) and bit error rate (BER). Closed-form expressions for the average received SNR and BER are derived. We show that these expressions are also applicable for slow fading scenarios. Numerical results demonstrate the negative affects of error floor on system performance under fast fading channels. For coherent detection, we show that increasing the channel estimation rate improves performance and reduces the error floor especially when higher diversity order is used. For differentially coherent detection, with low channel estimation rates, the results reveal that increasing diversity order reduces error floor compared to coherent detection. Our results also show that MRC provides better performance compared to SC irrespective of the value of the correlation parameter, the channel estimation rate, and the used modulation scheme.

Key-Words: - Fast fading; Error floor, SIMO, BPSK.

1. Introduction

Achieving high transmission rates with best BER performance at high speed in wireless mobile communication systems is a challenging problem. It is known that the effect of Doppler shift increases with mobile speed, which makes the wireless channel rapidly time-varying (fast fading). Such a fading channel can significantly degrade the performance of wireless systems. The effects of mobile speed on link performance have been well-studied in [1], [2], where a Markov process is used to capture the correlated nature of the channel. Specifically the authors showed that channel gain correlations, which are related to mobile speed, have a significant effect on system performance. The effect of mobile speed on wireless system performance is mainly represented by the error probability floor, which can be described as the scenario, where increasing the transmit power will not improve the BER performance. Error floor occurs in coherent system under fast-fading channel due to the fact that tracking loops at receivers cannot perfectly follow channel gains. To mitigate error floor in coherent detections, we can increase the channel estimation rate but this leads to spectral efficiency loss. Thus, in mobile applications, coherent detection is not preferred [3]. Differentially coherent modulation schemes also suffer from error floor problem under fast-fading channel [4] (In fast-fading scenario, it is hardly true that channel gains for two consecutive time slots are approximately constant).

The performance degradation of BPSK, BDPSK and binary frequency shift keying (BFSK) over flat-fast-Rayleigh fading channel was investigated in [5-7]. In this work, the channel is modeled as a first order autoregressive process. The main parameter that determines the fading characteristics (i.e., fast or slow) is the channel correlation parameter, which is inversely proportional to mobile speed. The results in [5] showed that the error floor severely degrade the performance of both coherent BPSK and coherent BFSK. In addition, BDPSK suffers from error floor, but with better performance than that of binary coherent detections. For noncoherent BFSK detection, it does not suffer from error floor, but with relatively bad performance at low SNR values compared with coherent and deferentially coherent schemes [8]. To find a detector that operates well in fast fading environment (i.e. does not suffer from error floor and provides better performance than coherent and noncoherent BFSK) the authors in [5] proposed the used of the partially coherent detection. It has been shown that applying diversity techniques significantly improves system performance under both slow and fast fading channels [9]. This improvement mainly depends on the employed modulation scheme and diversity technique, diversity branch correlations, diversity order, and channel fading rate [9].

Contributions: The main contribution of this paper is to investigate the effect of applying diversity on the performance of wireless mobile communication systems over i.i.d fast flat Rayleigh fading channels. Specifically, we assume uncorrelated and identically distributed L-order diversity channels, where each diversity channel is modeled as a first order autoregressive process. Using such model, closed form expressions for both average SNR and average BER for both BPSK and BDPSK with MRC and SC diversity receptions are derived. Based on the derived expressions, we investigate and quantify the effects of modulation scheme, diversity order, diversity technique, fading rate, and receiving channel estimation rate on error floor. Through numerical evaluation, we demonstrate that error floor reduction, which occurs due to high channel variation rates, can be realized using diversity.

The rest of the paper is organized as follows: section 2 describes the system model. In section 3, the system performance is studied in terms of the overall average SNR and BER. Performance evaluation and discussions are presented in 4. Finally, conclusions are summarized in 5.

2. System Model

We assume SIMO mobile wireless communication system with L-diversity channels. The L fading channels are i.i.d and each one is flat and fast Rayleigh. The channel over path l is modeled by a first order autoregressive (AR) process as in [5]:

$$g_k^{(l)} = \rho^{(l)} g_{k-1}^{(l)} + \sqrt{1-\rho^{(l)2}}\, w_k^{(l)},\ l = 1, 2, \cdots, L \tag{1}$$

where $\rho^{(l)}$ is the channel correlation parameter for branch number l. It is related to mobile speed by Jakes model [9]. All diversity branches are assumed to have same correlation parameter value, i.e., $\rho^{(l)} = \rho$, where $l = 1, 2, \cdots, L$. The transmitted bit at time slot k (x_k) over branch l experiences channel gain $g_k^{(l)}$. Let $w_k^{(l)}$ represents the varying component of channel l. This varying component is described by an i.i.d random process with same distribution for all branches (i.e., $CN(0,1)$, where CN indicates to circular symmetric Gaussian noise). The received symbol at branch l corresponds to the transmitted symbol x_k can be written as:

$$y_k^{(l)} = g_k^{(l)} x_k + n_k^{(l)} \tag{2}$$

where $n_k^{(l)}$ is a complex AWGN, with density of $CN(0, N_o)$, that affects the l^{th} replica of the transmitted symbol x_k. This noise is statistically independent for all branches and also independent of channel gains $g_k^{(l)}\}_{l=1}^{L}$.

In our analysis, we assume accurate channel estimation rate over each diversity branch every N data symbols (i.e., the transmitter sends a block of N data symbols and the receiver can perfectly determine the channel gain of the first symbol in a block ($g_o^{(l)}$)). Because we assume $g_o^{(l)}$ has density of $CN(0,1)$, then $\left|g_o^{(l)}\right|$ and $\left|g_o^{(l)}\right|^2$ are respectively Rayleigh and exponential random variables with probability density functions (pdf) given by:

$$f_{|g_o^{(l)}|}(x) = 2xe^{-x^2}, \quad x \geq 0.$$
$$f_{|g_o^{(l)}|^2}(x) = e^{-x}, \quad x \geq 0. \tag{3}$$

Based on the above discussion and using (1), the estimated channel gain over branch l at time slot k ($\hat{g}_k^{(l)}$) is given by:

$$\hat{g}_k^{(l)} \sim CN(\rho^k g_o^{(l)}, 1-\rho^{2k}). \tag{4}$$

3. Performance Analysis

3.1 BPSK with MRC Diversity Reception

We assume baseband notation and symbol-by-symbol detection throughout the paper. For BPSK transmission, the transmitted bit is given as:

$$x_k = \pm\sqrt{E_b} \tag{5}$$

where E_b is the bit energy. The MRC combiner equalizes the phase of $y_k^{(l)}$ by multiplying it with the conjugate of $g_o^{(l)}$. Then, it sums these multiplications for all l. The output represents the decision variable $r_k^{(BPSK)}$, which is given by:

$$r_k^{(BPSK)} = \sum_{l=1}^{L} g_o^{*(l)} y_k^{(l)} = (\pm\sqrt{E_b})\sum_{l=1}^{L} g_o^{*(l)} g_k^{(l)} + \sum_{l=1}^{L} g_o^{*(l)} n_k^{(l)} \tag{6}$$

where $(*)$ indicates the conjugate operation.

By substituting the distributions of $n_k^{(l)}$ and $\hat{g}_k^{(l)}$ in (6), the density of $r_k^{(BPSK)}$ can be expressed as:

$$r_k^{(BPSK)} \sim CN(\rho^k(\pm\sqrt{E_b})\sum_{l=1}^{L}\left|g_o^{(l)}\right|^2, (1-\rho^{2k})E_b\sum_{l=1}^{L}\left|g_o^{(l)}\right|^2 + N_o\sum_{l=1}^{L}\left|g_o^{(l)}\right|^2) \tag{7}$$

The expression of $r_k^{(BPSK)}$ in (7) can be rewritten in terms of the effective noise $Z_k^{(BPSK)}$ as follows:

$$r_k^{(BPSK)} = \rho^k(\pm\sqrt{E_b})\sum_{l=1}^{L}\left|g_o^{(l)}\right|^2 + Z_k^{(BPSK)} \tag{8}$$

where

$$Z_k^{(BPSK)} \sim CN\left(0, ((1-\rho^{2k})E_b + N_o)\sum_{l=1}^{L}\left|g_o^{(l)}\right|^2\right)$$

Using (8), the instantaneous effective MRC combiner output SNR can be found as follow:

$$\gamma^{(BPSK)}(k) = \frac{\left(\rho^k(\pm\sqrt{E_b})\sum_{l=1}^{L}\left|g_o^{(l)}\right|^2\right)^2}{(1-\rho^{2k})E_b + N_o)\sum_{l=1}^{L}\left|g_o^{(l)}\right|^2} = \frac{\rho^{2k}E_b\sum_{l=1}^{L}\left|g_o^{(l)}\right|^2}{(1-\rho^{2k})E_b + N_o}. \tag{9}$$

In addition, the overall instantaneous effective output SNR for the N-symbol block is given by:

$$\gamma^{(BPSK)} = \frac{\sum_{k=1}^{N}\gamma^{(BPSK)}(k)}{N} = \frac{\sum_{l=1}^{L}\left|g_o^{(l)}\right|^2}{N}\sum_{k=1}^{N}\frac{(E_b/N_o)\rho^{2k}}{1+(1-\rho^{2k})(E_b/N_o)}. \tag{10}$$

where the term $\sum_{l=1}^{L}\left|g_o^{(l)}\right|^2$ represents a chi-squared random variable with 2L degrees of freedom, and has the following pdf:

$$f_{\sum_{l=1}^{L}\left|g_o^{(l)}\right|^2}(x) = \frac{x^{L-1}e^{-x}}{(L-1)!}, \quad x \geq 0. \tag{11}$$

By averaging (10) over the distribution of $\sum_{l=1}^{L}\left|g_o^{(l)}\right|^2$, we can derive the overall average effective output SNR as follows:

$$\Gamma^{(BPSK)} = \frac{L}{N}\sum_{k=1}^{N}\frac{(E_b/N_o)\rho^{2k}}{1+(1-\rho^{2k})(E_b/N_o)}\cdot \quad (12)$$

From (8), the decision statistic at the MRC combiner output is given by:

$$\Re e\left\{\frac{r_k^{(BPSK)}}{\sqrt{\sum_{l=1}^{L}\left|g_o^{(l)}\right|^2}}\right\} = \rho^k(\pm\sqrt{E_b})\sqrt{\sum_{l=1}^{L}\left|g_o^{(l)}\right|^2} + \tilde{Z}_k^{(BPSK)} \quad (13)$$

where

$$\tilde{Z}_k^{(BPSK)} = \Re e\left\{\frac{Z_k^{(BPSK)}}{\sqrt{\sum_{l=1}^{L}\left|g_o^{(l)}\right|^2}}\right\} \sim N\left(0, \frac{(1-\rho^{2k})E_b+N_o}{2}\right)\cdot$$

Using (13), the instantaneous BER at time slot k can be expressed as:

$$p_e^{(BPSK)}(k) = Q\left(\sqrt{2\Gamma_{BPSK}^{(l)}(k)\sum_{l=1}^{L}\left|g_o^{(l)}\right|^2}\right) \quad (14)$$

where $\Gamma_{BPSK}^{(l)}(k)$ represents the average SNR per branch for the kth symbol, i.e.,

$$\Gamma_{BPSK}^{(l)}(k) = \frac{E_b\rho^{2k}}{(1-\rho^{2k})E_b+N_o}\cdot$$

Using (14), we can find the overall average BER as follows:

$$\overline{p}_e^{(BPSK)} = \frac{\sum_{k=1}^{N}\mathrm{E}\left[p_e^{(BPSK)}(k)\right]}{N} = \frac{\sum_{k=1}^{N}\int_0^{\infty}Q(\sqrt{2\Gamma_{BPSK}^{(l)}(k)x})f_X(x)dx}{N}\cdot \quad (15)$$

By evaluating the integration in (15) as in [11], [12], the overall average BER can be expressed as follows:

$$\overline{p}_e^{(BPSK)} = \frac{1}{N}\sum_{k=1}^{N}\left(\left(\frac{1-\sqrt{\chi}}{2}\right)^L\sum_{l=0}^{L-1}\binom{L-1+l}{l}\left(\frac{1+\sqrt{\chi}}{2}\right)^l\right) \quad (16)$$

where $\chi = \dfrac{\rho^{2k}E_b}{E_b+N_o}\cdot$

3.2 BDPSK with MRC Diversity Reception

For conventional binary DPSK the transmitted phase at certain time slot depends on the phase transmitted at the previous time slot. Therefore, the transmitted symbol at time slot $k+1$ is $x_{k+1} = d_{k+1}x_k$, where $d_{k+1} = \pm\sqrt{E_b}$, and $x_k \in \{+1,-1\}$. For BDPSK, the decision variable at the MRC combiner output, at time slot k, can be approximated as follows:

$$r_k^{(BDPSK)} = \sum_{l=1}^{L}\overset{*}{y}_k^{(l)}\, y_{k+1}^{(l)} \approx \rho^k(\pm\sqrt{E_b})\sum_{l=1}^{L}\left|g_k^{(l)}\right|^2 + Z_k^{(BDPSK)} \quad (17)$$

where

$$Z_k^{(BDPSK)} = \sum_{l=1}^{L}(\sqrt{1-\rho^2}\,d_{k+1}\,\overset{*}{g}_k^{(l)}\,w_{k+1}^{(l)} + \overset{*}{g}_k^{(l)}\,\overset{*}{x}_k\,n_{k+1}^{(l)} + \rho x_{k+1}g_k^{(l)}\,\overset{*}{n}_k^{(l)})$$
$$\sim CN\left(0,((1-\rho^2)E_b+(1+\rho^2)N_o)\sum_{l=1}^{L}\left|g_k^{(l)}\right|^2\right)\cdot$$

The approximation in (17) is performed by neglecting the products of $w_k^{(l)}\overset{*}{n}_k^{(l)}$ and $\overset{*}{n}_{k+1}^{(l)}\overset{*}{n}_k^{(l)}$ as in [10]. From (17), we can write the instantaneous effective output SNR as follows:

$$\gamma^{(BDPSK)} = \frac{\rho^2E_b\left|\sum_{l=1}^{L}g_k^{(l)}\right|^2}{(1-\rho^2)E_b+(1+\rho^2)N_o}\cdot \quad (18)$$

As in [5], the average effective output SNR can be written as

$$\Gamma^{(BDPSK)} = \mathrm{E}\left[\gamma^{(BDPSK)}\right] = \frac{\rho^2 E_b \mathrm{E}\left[\left(\sum_{l=1}^{L}\left|g_k^{(l)}\right|^2\right)\right]}{(1-\rho^2)E_b + (1+\rho^2)N_o} = \frac{L\rho^2 E_b}{(1-\rho^2)E_b + (1+\rho^2)N_o}. \quad (19)$$

We now, determine the output decision statistic as follows

$$\Re e\left\{\frac{r_k^{(BDPSK)}}{\sqrt{\sum_{l=1}^{L}\left|g_k^{(l)}\right|^2}}\right\} = \rho^k(\pm\sqrt{E_b})\sqrt{\sum_{l=1}^{L}\left|g_k^{(l)}\right|^2} + \tilde{Z}_k^{(BDPSK)} \quad (20)$$

where $\tilde{Z}_k^{(BDPSK)} = \Re e\left\{\frac{Z_k^{(BDPSK)}}{\sqrt{\sum_{l=1}^{L}\left|g_k^{(l)}\right|^2}}\right\}$, and has density of

$$N\left(0, ((1-\rho^2)E_b + (1+\rho^2)N_o)\frac{\sum_{l=1}^{L}\left|g_k^{(l)}\right|}{2}\right).$$

From (20), the instantaneous BER at time k is given by:

$$p_e^{(BDPSK)} = Q\left(\sqrt{2\Gamma_{BDPSK}^{(l)}\sum_{l=1}^{L}\left|g_k^{(l)}\right|^2}\right) \quad (21)$$

where $\Gamma_{BDPSK}^{(l)}$ represents average SNR per branch, and it is given by:

$$\Gamma_{BDPSK}^{(l)} = \frac{\rho^2 E_b}{(1-\rho^2)E_b + (1+\rho^2)N_o}.$$

By averaging $p_e^{(BDPSK)}$ over $\sum_{l=1}^{L}\left|g_k^{(l)}\right|^2$, we get the average BER for BDPSK with MRC diversity reception as follows:

$$\overline{p}_e^{(BDPSK)} = \left(\frac{1-\sqrt{\upsilon}}{2}\right)^L \sum_{l=0}^{L}\binom{L-1+l}{l}\left(\frac{1+\sqrt{\upsilon}}{2}\right)^l \quad (22)$$

where $\upsilon = \frac{\rho^2 E_b}{(1+\rho^2)N_o + E_b}$.

3.3 BPSK with SC Diversity Reception

Note that with SC receiver, the combiner selects the branch with the largest SNR and then demodulates the signal at that branch. Hence, the instantaneous effective SNR at the SC combiner output is determined according to the following formula [10]:

$$\gamma_{sc}(k) = \max\left\{\gamma^{(1)}(k),\, \gamma^{(2)}(k),\, \cdots,\, \gamma^{(L)}(k)\right\} \quad (23)$$

where $\gamma^{(l)}(k)$ is the instantaneous SNR per branch. For BPSK, the instantaneous SNR for symbol position k at branch *l* and its pdf are respectively given as:

$$\gamma_{BPSK}^{(l)}(k) = \Gamma_{BPSK}^{(l)}(k)\left|g_o^{(l)}\right|^2,\ l = 1, 2, \cdots, L \quad (24)$$

$$f_{\gamma_{BPSK}^{(l)}(k)}(x) = \frac{1}{\Gamma_{BPSK}^{(l)}(k)}\exp\left(\frac{-x}{\Gamma_{BPSK}^{(l)}(k)}\right), x \geq 0. \quad (25)$$

The pdf of the instantaneous effective SNR at the SC combiner output for BPSK $\gamma_{sc}^{(BPSK)}(k)$ is given by [11]:

$$f_{\gamma_{SC}^{(BPSK)}(k)}(x) = \frac{L}{\Gamma_{BPSK}^{(l)}(k)}\left(1-\exp\left(\frac{-x}{\Gamma_{BPSK}^{(l)}(k)}\right)\right)^{L-1} \times \exp\left(\frac{-x}{\Gamma_{BPSK}^{(l)}(k)}\right), x \geq 0. \quad (26)$$

Hence, the overall average effective output SNR for BPSK with SC reception can be computed as:

$$\Gamma_{SC}^{(BPSK)} = \frac{\sum_{k=1}^{N} \mathrm{E}\left[\gamma_{SC}^{(BPSK)}(k)\right]}{N} = \sum_{k=1}^{N} \frac{E_b \rho^{2k} \sum_{j=1}^{L} j}{N((1-\rho^{2k})E_b + N_o)}. \quad (27)$$

For BPSK, the instantaneous BER with SC reception, at time slot k, is given by:

$$p_{eSC}^{(BPSK)}(k) = Q\left(\sqrt{2\gamma_{SC}^{(BPSK)}(k)}\right). \quad (28)$$

Given (28), the overall average BER can be determined as:

$$\overline{P}_{eSC}^{(BPSK)} = \frac{1}{N}\sum_{k=1}^{N}\int_0^\infty Q(\sqrt{2x})\, f_{\gamma_{SC}^{(BPSK)}(k)}(x)dx$$
$$= \frac{1}{N}\sum_{k=1}^{N}\frac{L}{\Gamma_{BPSK}^{(l)}(k)}\sum_{l=0}^{L-1}\left(\binom{L-1}{l}(-1)^l \int_0^\infty Q(\sqrt{2x})\cdot \exp\left(\frac{-(1+l)x}{\Gamma_{BPSK}^{(l)}(k)}\right)dx\right). \quad (29)$$

Using integration by parts and the following identity:

$$\int_0^\infty x^{n-1}\exp\left(-(1+a)x\right)dx = \frac{\Gamma(n)}{(1+a)^n}.$$

The term $\overline{p}_{eSC}^{(BPSK)}$ can be rewritten as:

$$\overline{P}_{eSC}^{(BPSK)} = \frac{L}{2N}\sum_{k=1}^{N}\sum_{l=0}^{L-1}\left(\binom{L-1}{l}(-1)^l \frac{\left(1-\sqrt{\eta}\right)}{(1+l)}\right) \quad (30)$$

where $\eta = \dfrac{\rho^{2k}E_b}{(1+l)((1-\rho^{2k})E_b + N_o) + \rho^{2k}E_b}$.

3.4 BDPSK with SC Diversity Reception

For BDPSK, the average SNR per branch, which is the same for all symbols in given block, is given by:

$$\Gamma_{BDPSK}^{(l)} = \frac{\rho^2 E_b}{(1-\rho^2)E_b + (1+\rho^2)N_o}. \quad (31)$$

By replacing $\Gamma_{BPSK}^{(l)}(k)$ in (25) by $\Gamma_{BDPSk}^{(l)}$, and then re-evaluating the expectation in (26) and the integration in (28), we can respectively get the average output SNR and the average BER for BDPSK with SC diversity reception as follows:

$$\Gamma_{SC}^{(BDPSK)} = \frac{\rho^2 E_b \sum_{j=1}^{L} j}{(1-\rho^2)E_b + (1+\rho^2)N_o} \quad (32)$$

$$\overline{p}_{eSC}^{(BDPSK)} = L\sum_{l=0}^{L-1}\left(\binom{L-1}{l}(-1)^l \frac{\left(1-\sqrt{\xi}\right)}{2(1+l)}\right) \quad (33)$$

where

$$\xi = \frac{\rho^2 E_b}{(1+l)((1-\rho^2)E_b + (1+\rho^2)N_o) + \rho^2 E_b}.$$

4. Performance Evaluation and Discussions

In this section, we investigate the effect of the different system parameters on system performance. These parameters include: the diversity order L, the channel estimation rate (equivalently, the block size N), and the channel correlation parameter ρ, which is inversely proportional to the channel fading rate and has values between 0 and 1 (when $\rho = 1$, the channel is slow). According to Jakes' model, ρ is inversely proportional to mobile speed or to carrier frequency, and directly proportional to data rate. In realistic applications, the values of ρ are very close to one. For example, ρ is between 0.98 and 0.998 at mobile speed of 80 mph, data rate between 2.4 kbps and 9.6 kbps, and carrier frequency of 900 MHz [9]. In addition, for 64 kbps data rate, ρ stays greater than 0.9999 for mobile speeds less than 150 mph, and we can consider the fading channel almost slow for this range. The fading channel is considered rapidly time varying for $\rho < 0.999$ and considered in medium scale fast fading for $0.999 < \rho < 0.9999$.

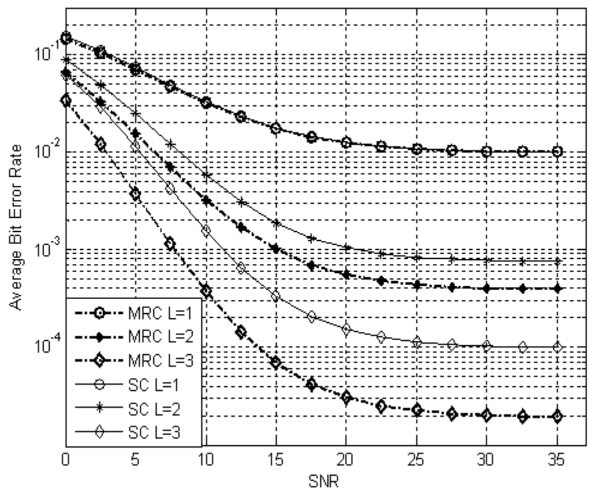
Figures 1.a and 1.b respectively plot the average BER versus SNR for BPSK and BDPSK with MRC and SC diversity receptions. It is clear that MRC provides better performance compared to SC irrespective of L. These figures reveal that under fast fading scenarios, the performance is largely affected by error floor. The performance is improved and the error floor is reduced by increasing diversity order irrespective of the employed diversity technique. Figure 2.a compares coherent and differentially coherent detections with diversity, in terms of error floor. For any value of L, the performance of BPSK is better than that of BDPSK at low SNR. Moreover, under high SNR, BDPSK has performance better than BPSK. Note that, performance improvement with L for BDPSK is better than BPSK in terms of error floor. Hence, differential detection is preferable to be used over fast fading channels with lower estimation rate. Figure 2.b shows that the performance of coherent BPSK, over fast fading channel, becomes better than that of BDPSK for larger values of SNR by increasing channel estimation rate. This figure also indicates that error floor reduction is possible by increasing channel estimation rate. Even though $N = 1$, error floor elimination cannot be realized when $\rho < 1$.

Figure 3 shows that increasing the value of L increases the reduction level of error floor. It is known that increasing channel estimation rate improves performance of coherent detection. The rate of this improvement is greater for higher diversity orders (see Figure 4.a). For any channel estimation rate, the performance of coherent detection is improved with increasing ρ. The positive effects of increasing the channel estimation rate appears much well when ρ is small (Fig 4.b).

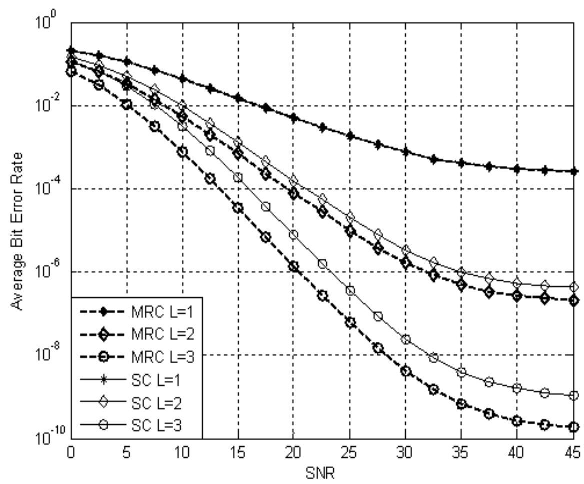
Figures 5.a and 5.b show that increasing channel correlation parameter reduces the error floor for both coherent and differentially coherent detections and this reduction is greater at higher L. Figure 6 shows that the performance of coherent detection becomes better than that of differentially coherent detection when ρ is closer to 1.

5. Conclusion

In this paper, we investigated the performance of wireless mobile communication system over i.i.d fast-flat Rayleigh fading channels with diversity reception. Closed form expressions for both average SNR and average BER for both BPSK and BDPSK with MRC and SC diversity receptions were derived. Results demonstrated that error floor reduction, which occurs due to high channel variation rates, can be realized using diversity. Specifically, the reduction level for BDPSK is greater than that of coherent BPSK with increasing number of diversity branches. For coherent detection, our results showed that increasing channel estimation rate can reduce error floor to a desirable level. Finally, we showed that MRC provides better performance compared to SC irrespective of channel variation rate or estimation rate.

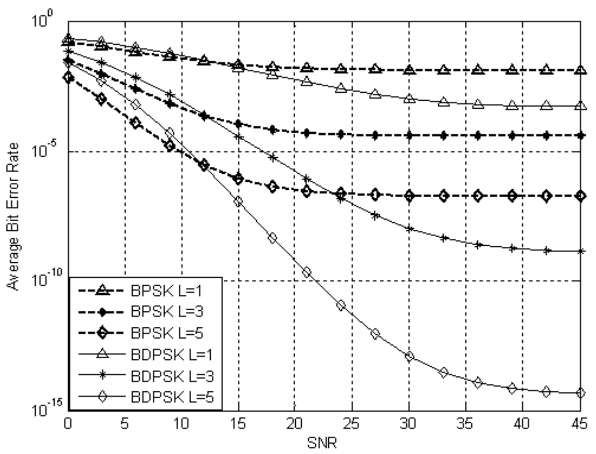


(a)

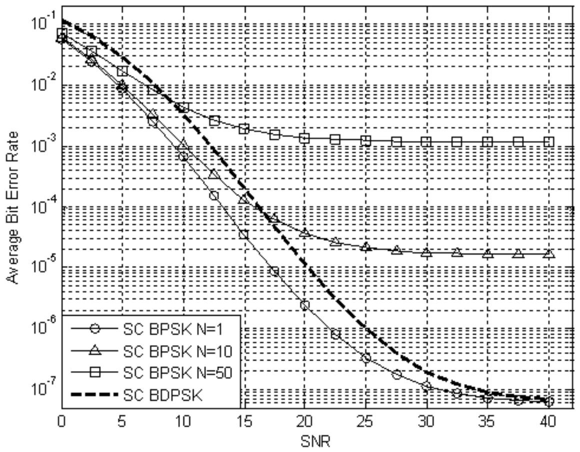


(b)

Figure 1: Average BER versus SNR with MRC and SC for ρ = 0.9995, N = 80, and L = {1, 2, 3}, (a) For BPSK, (b) For BDPSK.



(a)



(b)

Figure 2: Average BER versus SNR for BPSK and BDPSK, (a): with MRC, and for $\rho = 0.999$, $N = 50$ and $L = \{1, 3, 5\}$, (b): with SC, $\rho = .998$, L=3 and $L = \{1, 10, 50\}$.

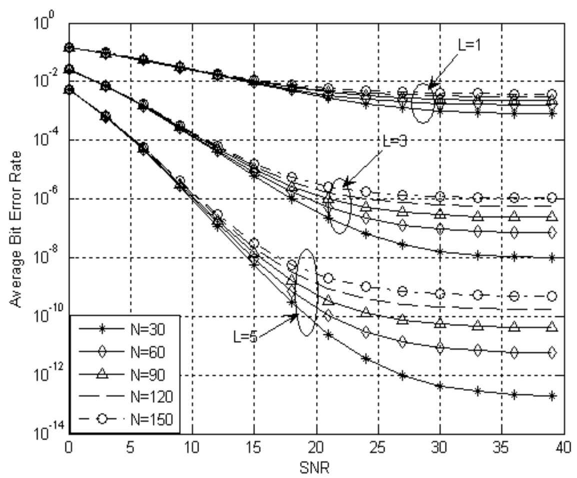
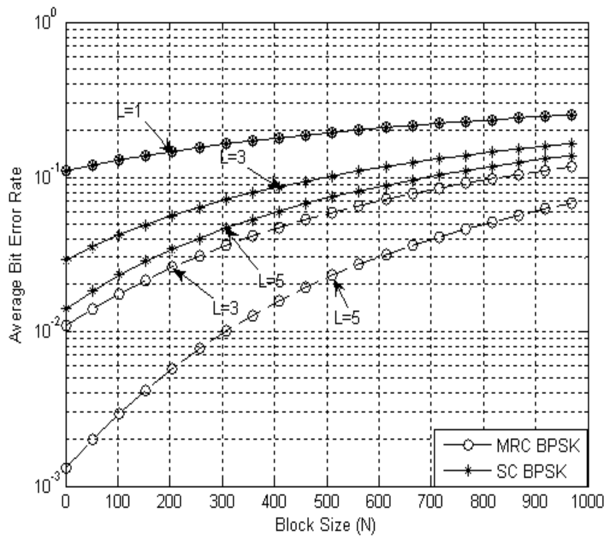
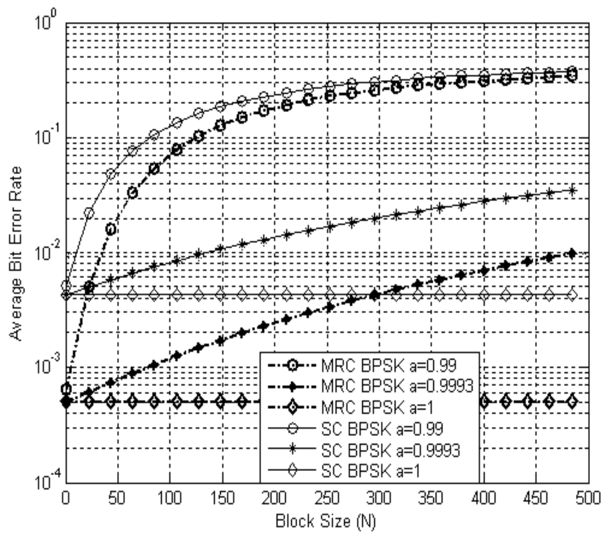


Figure 3: Average BER versus SNR for BPSK with MRC for $\rho = 0.9999$, $L = \{1, 3, 5\}$ and $N = \{30, 60, 90, 120, 150\}$.



(a)



(b)

Figure 4: Average BER versus the block size (N) for BPSK with MRC and SC, (a) for $\rho = 0.999$, $L = \{1, 2, 3\}$ and SNR = 2dB, (b) for $L = 4$, SNR = 5 dB and $\rho = \{0.99, 0.9993, 1\}$

References:

[1] M. J. Chu and W. E. Stark, “Effect of Mobile Velocity on Communications in Fading Channels,” IEEE Transactions on Vehicular Technology, vol. 49, no. 1, pp. 202–210, January 2000.

[2] Tepedelenlioglu, C.; Giannakis, G.B., "On velocity estimation and correlation properties of narrow-band mobile communication channels," IEEE Transactions on Vehicular Technology, vol.50, no.4, pp.1039-1052, Jul 2001.

[3] K. Hirade. Mobile communications. in K. Feher, Advanced Digital Communication Systems and Signal Processing Technique. Englewood Cliffs, NJ: Prentice-Hill; 1987.

[4] Pooi Yuen K m, “Bit Error Probabilities of MDPSK Over the Nonselective Rayleigh Fading Channel with Diversity Reception,” IEEE Transactions on Communications, vol. 39. no. 2. February 1991.

[5] Krishna Srikanth Gomadam and Syed Ali Jafar, “Modulation and Detection for Simple Receivers in Rapidly Time-Varying Channels,” IEEE Transactions on Comm., vol. 55, no. 3, pp. 529-539, 2007.

[6] Krishna Srikanth Gomadam; Jafar, S.A., "Partially coherent detection in rapidly time varying channels," IEEE Wireless Communications and Networking Conference, 2006 (WCNC) , 2006.

[7] Modh, N.M.; Parmar, K.R., "Performance analysis of receive diversity technique for wireless systems using partial channel knowledge," International Conference on Signal Processing and Communications (SPCOM), July 2012.

[8] D. Chen and J. N. Laneman, “Noncoherent demodulation for cooperative diversity in wireless systems,” in Proc. Globecom, Dallas, TX, 2004.

[9] W. C. Jakes and D. C. Cox, eds., Microwave Mobile Communications. Wiley-IEEE Press, 1994.

[10] J. G. Proakis, Digital Communications. New York: McGraw-Hill, 4th ed., 2001

[11] A. Goldsmith., Wireless Communications. Cambridge University Press; 2005.

[12] T. Rappaport, Wireless Communications: Principles and Practice. Upper Saddle River, NJ: Prentice-Hall, 2001.

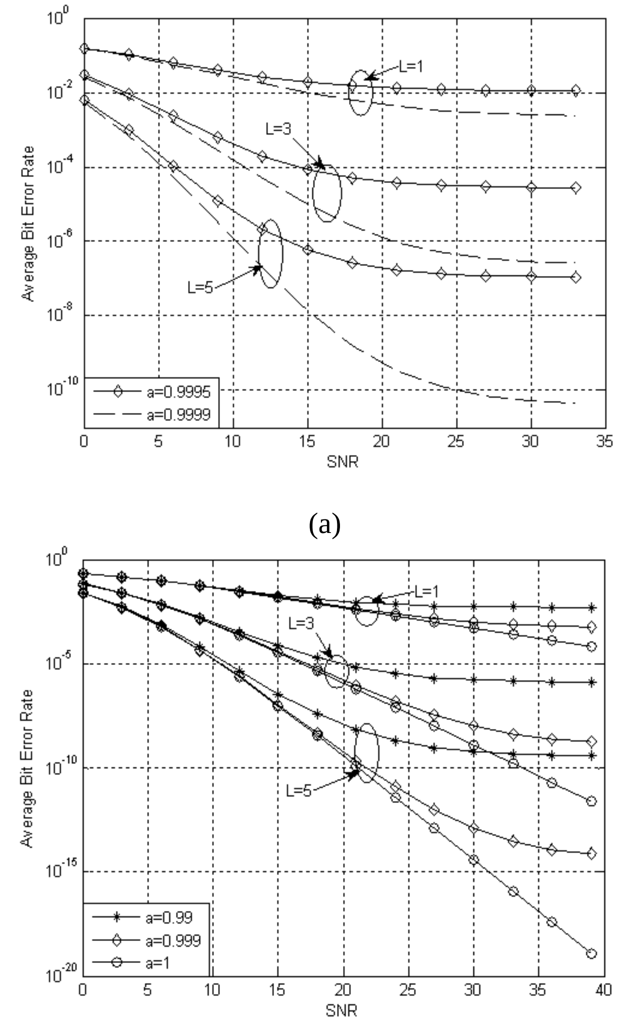


Figure 5: Average BER versus SNR with MRC, (a) for BPSK, N = 90, L = {1, 3, 5} and ρ = {0.9995, 0.9999}, (b) for BDPSK, L = {1, 3, 5} and ρ = {0.99, 0.999, 1}.

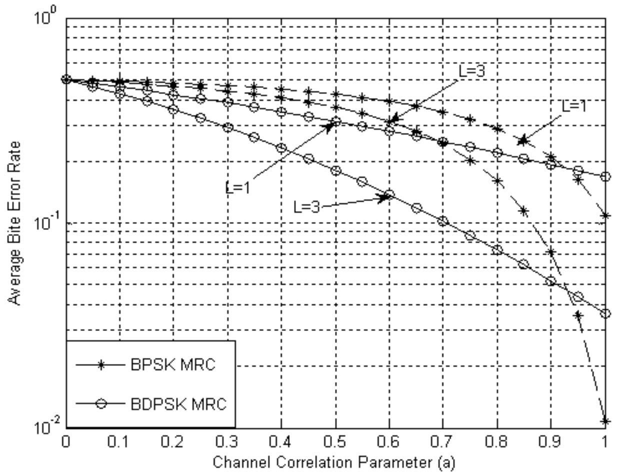


Figure 6: Average bit error rate versus channel correlation parameter for BPSK and BDPSK with MRC for SNR = 2 dB, N = 5 and L = {1, 3}.