On Optimum End-to-End Distortion in Delay-Constrained Wideband MIMO Systems

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***Abstract*—In this work, we analyze the optimum expected end-to-end distortion (EED) in delay-constrained wideband multiple-input mulitple-output (MIMO) systems. We prove that the existence of frequency diversity benefits the EED in delay-constrained systems though it does not impact the ergodic channel capacity. For further analysis, we derive the closed-form expression of the optimum asymptotic expected EED, comprised of the optimum distortion exponent and the multiplicative optimum distortion factor. We present that, the optimum asymptotic expected EED decreases monotonically with frequency diversity order, but EED does not vanish with infinite frequency diversity. We also investigate the impact of spatial correlation on EED in wideband systems. The theoretical results in this paper can be guidelines for practical wideband system design.**

I. Introduction

Generally, in analog-source transmission, end-to-end distortion (EED), *i.e.*, the distortion in the recovered analog source at the receiver, is the primary metric to measure the performance of an entire transmission system including source and channel coding. The distortion exponent in the optimum expected EED is derived in [1]–[3] for transmitting a white Gaussian source over spatially-uncorrelated block-fading flat MIMO channels under the delay constraint of the duration of a coherent channel block. In [4]–[6], we derived the optimum asymptotic expected EED comprised of the optimum distortion exponent and the multiplicative optimum distortion factor, for both cases of spatially uncorrelated and correlated block-fading flat channels. Concurrently, Tuninetti *et al.* also showed that the spatial correlation degrades the achievable expected EED in power-offset, *i.e.*, multiplicative distortion factor, but does not affect the distortion exponent [7].

There are various transmission scenarios with different end-to-end bandwidth efficiencies which can be represented by *source-to-channel bandwidth ratios* (SCBR) W_s/W_c where W_s is the source bandwidth and W_c is the channel bandwidth. For instance, a video transmission system would be at a high SCBR, whereas the channel-parameter feedback procedure would be at a low SCBR. According to rate distortion theory, lower (higher) SCBR's lead to better (worse) optimum EED. In this work, we consider wideband MIMO systems with frequency diversity branches. Our interest is to answer that, for a specific SCBR, i.e. with the same end-to-end bandwidth efficiency, whether there are advantages of using a wideband system instead of a narrowband system, and if there is, what is the effect of the frequency diversity order. We study the following four aspects on this issue:

1) Optimum EED for any SNR;
2) Optimum asymptotic EED for moderately high SNR;
3) The effect of infinite frequency diversity branches;
4) The impact of spatial correlation.

Our results can be easily extended to the case of time interleaving, a counterpart to frequency diversity. So, it is not surprising to see that the optimum distortion exponent derived in this work with frequency diversity order is identical to the result in [8] with time diversity order. However, via introducing the multiplicative optimum distortion factor, we provide more detailed analysis on the impact of diversity order and thus could be guidelines on wideband system design.

Throughout the paper, vectors and matrices are indicated by bold, $|\mathbf{A}|$ denotes the determinant of matrix $\mathbf{A}$, $E_x\{\cdot\}$ denotes expectation over the random variable x, the superscript † denotes conjugate transpose, and $(a)_n$ denotes $\Gamma(a+n)/\Gamma(a)$.

II. System Model

Assume that a continuous-time white Gaussian source $s(t)$ of bandwidth W_s Hz and source power P_s Watts, $s(t) \sim \mathcal{N}(0, P_s)$, is to be transmitted over a frequency-selective block-fading N_t-input N_r-output channel of bandwidth W_c Hz. Accounting for the frequency selectivity, the channel is supposed to be divided into L independent subchannels of coherence bandwidth W_b Hz, *i.e.*, $W_c = LW_b$ [9]. The delay constraint is supposed to be the duration of a coherent channel block. Let $\hat{s}(t)$ denote the recovered source at the receiver.

As stated in [10, pp. 248-250], each subchannel can be represented by the samples taken $1/2W_b$ seconds apart, *i.e.*, each subchannel is used at $2W_b$ channel uses per second as a time-discrete channel. The output of the l^{th} subchannel for the t^{th} channel use is

$$\mathbf{y}_{t,l} = \mathbf{H}_l \mathbf{x}_{t,l} + \mathbf{n}_{t,l} \tag{1}$$

where $\mathbf{x}_{t,l} \in \mathbb{C}^{N_t}$ is the transmitted subband signal satisfying the long-term power constraint $E_t\left\{\mathbf{x}_{t,l}^\dagger \mathbf{x}_{t,l}\right\} = P_l$,

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$\mathbf{H}_l \in \mathbb{C}^{N_r \times N_t}$ is the subchannel matrix whose elements are distributed as $\mathcal{CN}(0,1)$, $\mathbf{n}_{t,l} \in \mathcal{C}^{N_t}$ is the additive white noise vector whose elements are distributed as $\mathcal{CN}(0, N_0)$, *i.e.*, the noise spectral density is $N_0/2$ Watts per Hz in each dimension of the complex subchannel. The total transmit power is supposed to be P Watts, *i.e.*, $\sum_{l=1}^{L} P_l = P$.

For uncorrelated channels, the elements in $\mathbf{H}_l$ are independent to each other. For spatially correlated channels, we assume the antennas are correlated at the transmitter but not the receiver. The covariance matrix $\mathbf{\Sigma} = E_{\mathbf{H}_l}\left\{\mathbf{H}_l\mathbf{H}_l^{\dagger}\right\}$ is supposed to be the same for all subbands and be a full rank matrix with its diagonal all 1's and distinct eigenvalues $\sigma = [\sigma_1, \sigma_2, \ldots, \sigma_{\mathrm{N_{min}}}]$, $0 < \sigma_1 < \sigma_2 < \ldots < \sigma_{N_{\min}}$. It can be seen that for uncorrelated channels, $\mathbf{\Sigma}$ is an identity matrix with $\sigma_1 = \sigma_2 = \ldots = \sigma_{N_{\min}} = 1$.

Under the assumption that the transmitter does not know the subchannel gains, the transmit power is equally allocated to the transmission over each subchannel, *i.e.*, $P_l = P/L$, $l = 1, \ldots, L$. With the noise power $N_0 W_b$ Watts, the SNR for each subchannel is

$$\rho_l = \frac{\frac{P}{L}}{N_0 W_b} = \frac{P}{N_0 W_c}. \tag{2}$$

It can be seen that the SNR for each subchannel is equal to the SNR for the whole channel, $\rho = P/N_0 W_c$.

The channel is supposed to be perfectly known at the receiver and the transmission system is assumed to be free of outage, *e.g.*, analog (continuous-parameter) transmission.

III. Main Results

A. Optimum EED for any SNR

Proposition 1: The existence of frequency diversity benefits the end-to-end distortion in delay-constrained systems.

Proof: We consider a delay-constrained system where the transmission rate is subject to the instantaneous channel capacity of the coherent channel block and cannot benefit from the ergodic channel capacity.

The instantaneous channel capacity is the sum of the subchannel capacities

$$R_c = \sum_{l=1}^{L} R_{b,l} \tag{3}$$

where the the capacity of the l^{th} subchannel is

$$R_{b,l} = 2W_b \log_2 \left|\mathbf{I}_{N_r} + \frac{\rho}{N_t}\mathbf{H}_l\mathbf{H}_l^{\dagger}\right| \tag{4}$$

where $W_b = W_c/L$.

The source rate of the white Gaussian source $s(t)$ is

$$R_s = W_s \log_2 \frac{P_s}{D} \tag{5}$$

where D is the mean squared error, *i.e.*, end-to-end distortion (EED)

$$D = \lim_{T\to\infty} \frac{1}{T}\int_0^T |s(t) - \hat{s}(t)|^2 \mathrm{d}t \tag{6}$$

[11].

Using Shannon's inequality [12] stretched to the block-fading case,

$$R_s \le R_c, \tag{7}$$

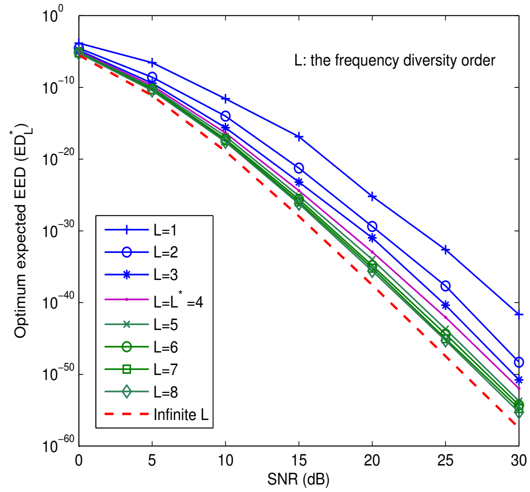

Fig. 1. The impact of frequency diversity on optimum expected EED. The channel is uncorrelated, $N_t = 4$, $N_r = 2$, $\eta = 0.2$, and P_s = 1

the optimum EED is

$$D_L^*(\eta) = P_s \prod_{l=1}^{L} \left|\mathbf{I}_{N_r} + \frac{\rho}{N_t}\mathbf{H}_l\mathbf{H}_l^{\dagger}\right|^{-\frac{2}{L\eta}} \tag{8}$$

where η is the source-to-channel bandwidth ratio (SCBR), $\eta = W_s/W_c$. Hence, the optimum expected end-to-end distortion is

$$ED_L^*(\eta) = P_s E_{\mathbf{H}_1,\cdots,\mathbf{H}_L}\left\{\prod_{l=1}^{L}\left|\mathbf{I}_{N_r} + \frac{\rho}{N_t}\mathbf{H}_l\mathbf{H}_l^{\dagger}\right|^{-\frac{2}{L\eta}}\right\}. \tag{9}$$

Since $\mathbf{H}_1, \cdots, \mathbf{H}_L$ are independent and identically distributed, we have

$$ED_L^*(\eta) = P_s\left[E_{\mathbf{H}}\left(\left|\mathbf{I}_{N_r} + \frac{\rho}{N_t}\mathbf{H}\mathbf{H}^{\dagger}\right|^{-\frac{2}{L\eta}}\right)\right]^L \tag{10}$$

where $\mathbf{H}$ denotes a flat Rayleigh-fading N_t-input N_r-output channel which is i.i.d. to $\mathbf{H}_1, \cdots, \mathbf{H}_L$.

From Jensen's inequality, we have that, for $L > 1$,

$$ED_L^*(\eta) < ED_1^*(\eta), \tag{11}$$

where $ED_1^*(\eta)$ represents the optimum expected EED in the delay-constrained system over a flat Rayleigh-fading N_t-input N_r-output channel. This result indicates that the existence of frequency diversity benefits the EED in delay-constrained systems. ■

From Proposition 1, we see that, though it is known that the ergodic capacity cannot be improved by increasing frequency diversity branches, the end-to-end distortion in delay-constrained systems can be improved by exploiting frequency diversity. In other words, for a specific SCBR η, *i.e.* with the same end-to-end bandwidth efficiency, a delay-constrained wideband system exploiting frequency diversity suffers less EED than a delay-constrained narrowband system with no frequency diversity to be exploited.

Assume the channel is uncorrelated, $N_t = 4$, $N_r = 2$, $\eta = 0.2$, and P_s = 1. In Fig.1, the impact of frequency diversity on the optimum expected EED is shown via evaluating (10) by Mont Carlo simulations. It can be seen that the optimum expected EED ED_L^* decreases with the frequency diversity order L and the effect is obvious in log-log scale when SNR is moderately high.

Although (11) indicates that the existence of frequency diversity benefits system, but it does not declare that end-to-end distortion decreases monotonically with frequency diversity order as shown in Fig.1. In the following discussion, we will prove that optimum asymptotic EED decreases with frequency diversity order.

B. Optimum asymptotic EED for moderately high SNR

The asymptotic expression of $ED_L^*(\eta)$ in the high SNR regime can be written as

$$ED_{L,\text{asy}}^*(\eta) = \mu_L^*(\eta)\rho^{-\Delta_L^*(\eta)} \tag{12}$$

with

$$\Delta_L^*(\eta) = \lim_{\rho\to\infty} \frac{\log ED_L^*(\eta)}{\log \rho}, \tag{13}$$

$$\lim_{\rho\to\infty} \frac{\log \mu_L^*(\eta)}{\log \rho} = 0 \tag{14}$$

On the other hand, the expression (10) can be rewritten as

$$ED_L^*(\eta) = P_s^{1-L}\left[ED_1^*(L\eta)\right]^L. \tag{15}$$

When $L = 1$, the analytical expression of $ED_1^*(\eta)$ has been given in [6]. Consequently, the analytical expression of $ED_L^*(\eta)$ is straightforward.

From (12) and (15), we have that

$$\Delta_L^*(\eta) = L\Delta_1^*(L\eta), \tag{16}$$

$$\mu_L^*(\eta) = P_s^{1-L}\mu_1^*(L\eta)^L. \tag{17}$$

In [6], the closed-form expressions of $\Delta_1^*(\eta)$ and $\mu_1^*(\eta)$ for both cases of spatially uncorrelated and correlated channels have been given. So, the SCBR regimes can be defined as follows:

- The low SCBR regime is defined as
$$\eta \in \left(0, \frac{2}{L(N_t+N_r-1)}\right); \tag{18}$$
- The moderate SCBR regime is defined as
$$\eta \in \left[\frac{2}{L(N_t+N_r-1)}, \frac{2}{L(|N_t-N_r|+1)}\right]; \tag{19}$$
- The high SCBR regime is defined as
$$\eta \in \left(\frac{2}{L(|N_t-N_r|+1)}, +\infty\right). \tag{20}$$

Proposition 2: The optimum distortion exponent Δ_L^* increases monotonically with frequency diversity order only when the frequency diversity order $L \leq L^*$ where $L^* = \left\lceil \frac{2}{\eta(|N_t-N_r|+1)} \right\rceil$; when $L > L^*$, increasing frequency diversity has no effect on Δ_L^*.

Proof: Consider the optimum distortion exponent Δ_L^*. When a system is in the low SCBR regime,

$$\Delta_L^* = LN_tN_r; \tag{21}$$

when a system is in the high SCBR regime,

$$\Delta_L^* = 2N_{\min}/\eta; \tag{22}$$

when a system is in the moderate SCBR regime,

$$\Delta_L^* = Ls(s+|N_t-N_r|) + \frac{2(N_{\min}-s)}{\eta} \tag{23}$$

with

$$s = \left\lfloor \frac{\frac{2}{\eta}+1-|N_t-N_r|}{2} \right\rfloor. \tag{24}$$

Related to (21), (22) and (23), when a system is in the low or moderate SCBR regime, the optimum distortion exponent Δ_L^* monotonically increases with frequency diversity order L; whereas, when a system is in the high SCBR regime, it has nothing to do with L. If a system is in the low SCBR regime when $L = 1$, related to the definitions of the SCBR regimes, increasing L continuously will make the system migrate into the moderate SCBR regime and finally into the high SCBR regime. The transit point from the moderate SCBR regime to the high SCBR regime is

$$L^* = \left\lceil \frac{2}{\eta(|N_t-N_r|+1)} \right\rceil, \tag{25}$$

beyond which the increase of frequency diversity has no effect on the optimum distortion exponent, *i.e.*, it does not affect the slope of $ED_{\text{L,asy}}^*$. ■

Proposition 3: When the frequency diversity order $L > L^*$, the optimum distortion factor μ_L^* decreases monotonically with L.

Proof: From (17), when a system is in the high SCBR regime, the optimum distortion factor is

$$\mu_L^* = P_sN_t^{\frac{2N_{\min}}{L\eta}}\left[\prod_{k=1}^{N_{\min}} \frac{\sigma_k^{-\frac{2}{\eta}}\Gamma(|N_t-N_r|-\frac{2}{L\eta}+k)}{\Gamma(|N_t-N_r|+k)}\right]^L. \tag{26}$$

Let

$$\varphi(L) = \prod_{k=1}^{N_{\min}} \frac{\sigma_k^{-\frac{2}{\eta}}\Gamma(|N_t-N_r|-\frac{2}{L\eta}+k)}{\Gamma(|N_t-N_r|+k)}. \tag{27}$$

Since $\varphi(L) < 1$ and $\frac{\mathrm{d}}{\mathrm{d}L}\varphi(L) > 0$, the derivative of μ_L^* with respect to L

$$\frac{\mathrm{d}}{\mathrm{d}L}\mu_L^* = P_sN_t^{\frac{2N_{\min}}{\eta}}\varphi(L)^L \ln\varphi(L) \cdot \frac{\mathrm{d}}{\mathrm{d}L}\varphi(L) < 0. \tag{28}$$

Namely, when a system is in the high SCBR regime, the optimum distortion factor μ_L^* monotonically decreases with L. ■

Proposition 4: The optimum asymptotic expected EED $ED_{L,\text{asy}}^*$ decreases monotonically with frequency diversity order.

Proof: It is a straightforward result with (12), Proposition 2 and 3. ■

Therefore, for a specific SCBR, *i.e.*, with the same end-to-end bandwidth efficiency, a delay-constrained wideband system

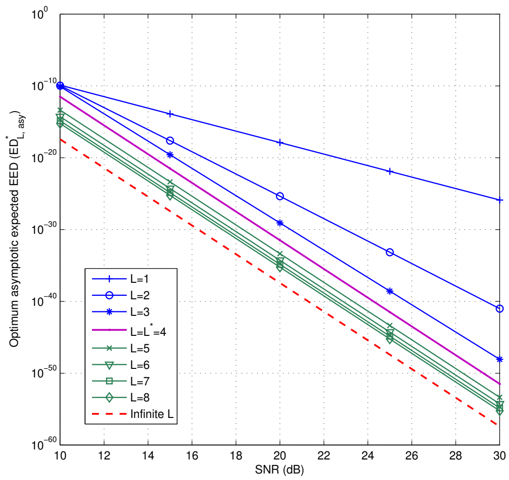

Fig. 2. The impact of frequency diversity on optimum asymptotic expected EED. The channel is uncorrelated, $N_t = 4$, $N_r = 2$, $\eta = 0.2$, and $P_s = 1$.

with more frequency diversity branches suffers less EED at moderately high SNR.

In Fig.2, the impact of frequency diversity on optimum asymptotic expected EED $ED^*_{L,\text{asy}}$ is shown by evaluating (12). The setting is the same as for Fig.1. Relating to Fig.1, we see that the tendency of asymptotic optimum expected EED with frequency diversity reflects the behavior of optimum expected EED. It can be seen that when $L > L^*$, the benefit from increasing frequency diversity is much less than when $L \leq L^*$.

From Fig.1 and Fig.2, we see that the asymptotic lines with $L = 3$ and $L = 4$ are very close to the curves of ED^*_L when SNR is greater than 20 dB and the asymptotic lines with $L > 4$ are very close to the curves of ED^*_L when the SNR is greater than 15 dB. It illustrates that for moderately high SNR, we can use the analysis based on the asymptotic EED instead of the EED because

$$ED^*_L \approx ED^*_{L,\text{asy}}. \tag{29}$$

With the closed form expression of asymptotic EED, the analysis on designing a system with good expected EED could be dramatically simplified.

C. EED cannot vanish with infinite frequency diversity

Proposition 5: The lower bound of the optimum expected EED with infinite frequency diversity is

$$\lim_{L\to\infty} ED^*_L = P_s\, 2^{-\frac{2}{\eta} E_{\mathbf{H}}\left(\log_2 \left|\mathbf{I}+\frac{\rho}{N_t}\mathbf{H}\mathbf{H}^\dagger\right|\right)}. \tag{30}$$

Proof: The ergodic capacity is

$$C = 2W_c E_{\mathbf{H}}\left(\log_2\left|\mathbf{I}+\frac{\rho}{N_t}\mathbf{H}\mathbf{H}^\dagger\right|\right) \tag{31}$$

where $\mathbf{H}$ denotes a flat Rayleigh fading MIMO channel.

A wideband channel with infinite frequency diversity can be treated as a fast-fading channel. Therefore, the lower bound on the optimum expected EED ED^*_L with $L = \infty$ is

$$\lim_{L\to\infty} ED^*_L = P_s\, 2^{-\frac{2}{\eta} E_{\mathbf{H}}\left(\log_2 \left|\mathbf{I}+\frac{\rho}{N_t}\mathbf{H}\mathbf{H}^\dagger\right|\right)}. \tag{32}$$

■

In Fig.1, the lower bound on ED^*_L is marked by the red dash line which is the lowest.

In the following, we focus on deriving a lower bound on the optimum asymptotic expected EED $ED^*_{L,\text{asy}}$ in closed form.

Lemma 1:

$$\lim_{L\to\infty}\left[\frac{\Gamma\left(n-\frac{a}{L}\right)}{\Gamma(n)}\right]^L = e^{a\gamma+\frac{a}{n}-\sum_{k=1}^{n}\frac{a}{k}}, \quad n\in\mathbb{N}, a\neq 0 \tag{33}$$

where γ is the Euler-Mascheroni constant.

Proof: Since the logarithm of the gamma function is

$$\ln\left[\Gamma(z)\right] = -\ln z - \gamma z + \sum_{k=1}^{\infty}\left[\frac{z}{k} - \ln\left(1+\frac{z}{k}\right)\right], \tag{34}$$

we have

$$\begin{aligned}
&\lim_{L\to\infty}\ln\left\{\left[\frac{\Gamma\left(n-\frac{a}{L}\right)}{\Gamma(n)}\right]^L\right\} \\
&= \lim_{L\to\infty} L\left[\ln\Gamma\left(n-\frac{a}{L}\right) - \Gamma(n)\right] \\
&= a\gamma + \frac{a}{n} - \sum_{k=1}^{n}\frac{a}{k}.
\end{aligned} \tag{35}$$

Therefore,

$$\lim_{L\to\infty}\left[\frac{\Gamma\left(n-\frac{a}{L}\right)}{\Gamma(n)}\right]^L = e^{a\gamma+\frac{a}{n}-\sum_{k=1}^{n}\frac{a}{k}}. \tag{36}$$

This concludes our proof. ■

Proposition 6: The lower bound of optimum asymptotic expected EED with infinite frequency diversity is

$$\begin{aligned}
&\lim_{L\to\infty} ED^*_{L,\text{asy}} \\
&= P_s N_t^{\frac{2N_{\min}}{\eta}} e^{\frac{2\gamma N_{\min}}{\eta}-\frac{2}{\eta}\sum_{k=1}^{N_{\min}} H_{|N_t-N_r|+k-1}} \prod_{k=1}^{N_{\min}} \sigma_k^{-\frac{2}{\eta}} \rho^{-\frac{2N_{\min}}{\eta}}.
\end{aligned} \tag{37}$$

where γ is the Euler-Mascheroni constant and H_n is the harmonic number with the order n,$H_n = \sum_{k=1}^{n}\frac{1}{k}$.

Proof: Since the system is in the high SCBR regime when L goes to infinity, By Lemma 1 , the optimum distortion factor

$$\lim_{L\to\infty}\mu^*_L = P_s N_t^{\frac{2N_{\min}}{\eta}} e^{\frac{2\gamma N_{\min}}{\eta}-\frac{2}{\eta}\sum_{k=1}^{N_{\min}} H_{|N_t-N_r|+k-1}} \prod_{k=1}^{N_{\min}} \sigma_k^{-\frac{2}{\eta}} \tag{38}$$

where γ is the Euler-Mascheroni constant and H_n is the harmonic number with the order n,$H_n = \sum_{k=1}^{n}\frac{1}{k}$.

Therefore, the lower bound on the optimum asymptotic expected EED $ED^*_{L,\text{asy}}$ is

$$\begin{aligned}
&\lim_{L\to\infty} ED^*_{L,\text{asy}} \\
&= P_s N_t^{\frac{2N_{\min}}{\eta}} e^{\frac{2\gamma N_{\min}}{\eta}-\frac{2}{\eta}\sum_{k=1}^{N_{\min}} H_{|N_t-N_r|+k-1}} \prod_{k=1}^{N_{\min}} \sigma_k^{-\frac{2}{\eta}} \rho^{-\frac{2N_{\min}}{\eta}}.
\end{aligned} \tag{39}$$

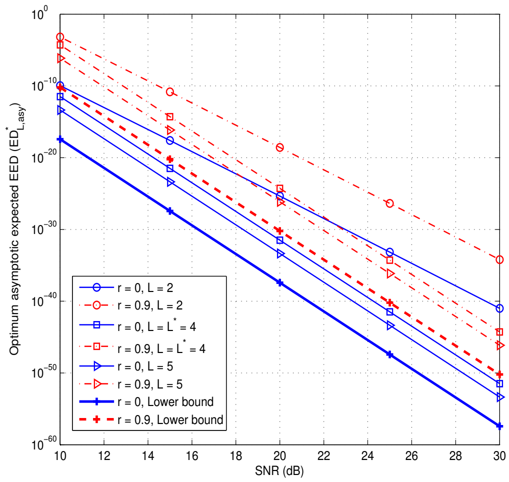

Fig. 3. The impact of spatial correlation on optimum asymptotic expected EED. $N_t = 4$, $N_r = 2$, $\eta = 0.2$, and $P_s = 1$.

■

In Fig.2, the lower bound on $ED^*_{L,\text{asy}}$ is marked by dash line.

From Fig.1 and Fig.2, we see that when L approaches infinite, for SNR > 10 dB, the lower bound on the optimum expected EED ED^*_L is almost overlapped by the lower bound on the optimum asymptotic expected EED $ED^*_{L,\text{asy}}$

$$\lim_{L\to\infty} ED^*_L \approx \lim_{L\to\infty} ED^*_{L,\text{asy}}. \quad (40)$$

That is, for a wideband MIMO system with high frequency diversity, for a large range of SNR, the analysis results on the asymptotic EED could be applied to the EED.

D. Impact of spatial correlation

Proposition 7: Spatial correlation always worsens optimum asymptotic EED in delay-constrained systems with frequency diversity, even if with infinite frequency diversity.

Proof: In [6], we have stated that the effect of spatial correlation on optimum asymptotic expected EED is only on the optimum distortion factor but not the optimum distortion exponent. The spatial correlation decreases the optimum distortion factor and thus worsens the optimum asymptotic EED. Since

$$\sum_{k=1}^{N_{\min}} \sigma_k^{-\frac{2}{\eta}} = N_{\min}, \quad (41)$$

in terms of the inequality between the arithmetic mean and the geometric mean, we have

$$\prod_{k=1}^{N_{\min}} \sigma_k < 1. \quad (42)$$

Hence, related to (39), we have

$$\lim_{L\to\infty} ED^*_{L,\text{asy,unc}} < \lim_{L\to\infty} ED^*_{L,\text{asy,cor}}. \quad (43)$$

■

Fig.3 shows the impact of spatial correlation on optimum asymptotic expected EED. In this example, we consider a well-known correlation model as in [13]: the exponential correlation with $\mathbf{\Sigma} = \{r^{|i-j|}\}_{i,j=1,\cdots,N_{\min}}$ and $r \in (0,1)$ [14].

IV. Conclusion

Our analysis on optimum expected EED and optimum asymptotic expected EED shows that increasing frequency diversity can always improve EED in delay-constrained block-fading MIMO systems. Therefore, with the same end-to-end bandwidth efficiency, a wideband system exploiting more frequency diversity branches is able to achieve less EED.

We derive a transit point beyond which increasing frequency diversity branches has no effect on the slope of optimum expected EED curve, i.e. the optimum distortion exponent, but on the offset, i.e. the multiplicative optimum distortion factor.

Considering infinite frequency diversity, we derive the lower bounds of optimum expected EED and optimum asymptotic expected EED. We also show the impact of spatial correlation on EED of wideband systems.

Although the results in this paper are derived under the assumption that the systems are free of outage, they can be loose bounds for outage-suffering systems.

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