Selection Diversity for Wireless Optical Communications with Non-coherent Detection without CSI

Hassan Moradi, *Student Member*, *IEEE*, Hazem H. Refai, *Member*, *IEEE*,
Peter G. LoPresti, *Member*, *IEEE*, Mohammed Atiquzzaman, *Senior Member*, *IEEE*

***Abstract*— The availability of Channel State Information (CSI) at the receiver side of a Free Space Optical (FSO) link is required for optimal detection and diversity combining. Consequently, providing instantaneous CSI knowledge introduces challenges to receiver design and an increase in estimation error and bandwidth waste. In this work we investigate two selection-combining diversity schemes and their achieved gains when perfect instantaneous CSI is not available. An average SNR estimation value at the receiver is used for branch selection, and signal combining is performed with branch balance and unbalance. Channel fading is modeled as a lognormal distribution with spatially correlated samples. BER performance and outage probabilities are analytically characterized. Further, analytical results are verified using computer simulation.**

***Index Terms*—** Free Space Optics (FSO), Channel state information (CSI), Spatial diversity, Selection combining (SC), Equal gain combining (EGC), Correlated channel.

I. INTRODUCTION

Space diversity has been widely investigated in the literature and includes several analytical reports assuming coherent [1] and non-coherent (direct) detections [2]. In wireless optical links, the channel changes slowly relative to symbol rate. In this case, pilot tones provide information about the channel. The chief advantages of optimal non-coherent detection when perfect CSI is available at the receiver side are the simplicity of the detector and lower bound to BER. However, diversity combining schemes based on perfect CSI availability is sensitive to channel estimation error, particularly for low SNR signals. Accordingly, Equal Gain Combining (EGC) can provide a solution when CSI is not available.

In this work, authors investigate the deployment feasibility of selection diversity (SC) categorized in single-in multiple-out (SIMO) systems, which translates into a higher link margin than for a single link. Channel coefficients are assumed spatially correlated, and two branch configuration cases, e.g. *balance* and *unbalance,* are considered. Optimal detection is utilized on the basis of CSI unavailability. In this case the detector is unaware of the exact instantaneous fading coefficients through the lognormal, distributed time-varying channel. The receiver, however, relies on SNR estimation when selecting the branch with the best quality and is performed based on maximum received SNR. This results in improved BER and outage probability performances when compared to EGC with branch unbalance. Wherever needed, the detection of the received signal is determined by conventional Symbol-by-Symbol detection [3].

Among previous works, Tsiftsis, *et al*. in [2] have investigated the BER of spatial diversity systems using EGC, optimal combining (OC), and SC. It has been assumed that perfect CSI is available for detection, and the atmospheric turbulence is modeled as *K* distribution. In [4], authors have mathematically studied the BER performance of diversity through FSO links for both independent and mutually correlated lognormal atmospheric turbulence channels in an EGC combining technique. Similar assumptions have been considered in [5], [6], [7], [8].

The balance of this paper is organized as follows. In Section II basic definitions and channel model assumptions are presented. Section III presents selection combining approaches assuming unavailability of CSI. Simulation results are presented in Section IV, and section V concludes the paper.

II. CHANNEL MODEL

The received signal $r[k]$ by On-OFF Keying modulation can be expressed by

$$r[k] = h[k]s[k] + v[k] \tag{1}$$

where $s[k] \in \{0,1\}$ is the transmitted signal, $h[k] > 0$ is the normalized time-varying and ergodic channel fading due to atmospheric turbulence, and $v[k]$ is total additive Gaussian noise. Assuming a discrete-time sampling, authors simply neglect term time $[k]$ in the analysis presented herein.

A. Noise and SNR Representation

The mean of the received signal r expressed as

$$E[r] = \begin{cases} I_1 & \text{if } s = 1 \\ I_0 & \text{if } s = 0 \end{cases} \tag{2}$$

while the variance of noise is given by

$$\text{var}(i_n) = E[v^2] - E^2[v] = \begin{cases} \sigma_1 & \text{if } s = 1 \\ \sigma_0 & \text{if } s = 0 \end{cases} \tag{3}$$

The fading channel coefficient, which models the channel from the transmit aperture to the receive aperture, is given by $h = e^{2X}$, in which log-amplitude χ is the identically

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H. Moradi and H. H. Refai are with the Electrical and Computer Engineering, University of Oklahoma, Tulsa, OK USA (phone: 918-660-3243; e-mails: hmoradi@ou.edu, hazem@ou.edu).

P. G. LoPresti is with the Electrical Engineering Department, University of Tulsa, Tulsa, OK USA (e-mail: pgl@ohm.ee.utulsa.edu).

M. Atiquzzaman is with the Computer Science, University of Oklahoma, Norman, OK USA (e-mail: atiq@ou.edu).

distributed normal random variable (RV) with mean μ_χ and standard deviation σ_χ. We assume $\mu_\chi = -\sigma_\chi^2$ to realize a normalized scintillation fading coefficient h with $E[h] = 1$. Authors refer to σ_χ as *fading strength* in this paper[1]. Subsequently, the instant electrical SNR will be defined by

$$\gamma \triangleq \left(\frac{I_1 - I_0}{\sigma_1 + \sigma_0}\right)^2 = \frac{4R^2h^2P_t^2}{(\sigma_1 + \sigma_0)^2} \tag{4}$$

where R is the receiver's responsivity, i.e. optical-to-electrical conversion coefficient, and P_t is the average of transmitted power[2]. For simplicity, we can assume $2RP_t = 1$ to conform Eq. (1). Mathematically speaking, the long-term average value of SNR is

$$\bar{\bar{\gamma}} \triangleq \int_0^\infty \gamma\, f_\gamma(\gamma) d\gamma \tag{5}$$

Alternatively, we use another definition for the average SNR in our analysis

$$\bar{\gamma} \triangleq \frac{4R^2P_t^2}{(\sigma_1 + \sigma_0)^2} \tag{6}$$

resulting

$$\gamma = \bar{\gamma}h^2 \tag{7}$$

B. Fading Model

In terms of wireless optical communications, several fading models are considered for representing scintillation statistics through probability distribution. Most commonly known, lognormal distribution has a probability distribution function (PDF) and is

$$f_h(h) = \frac{1}{\sqrt{8\pi}h\sigma_\chi}\exp\left(-\frac{\left(\ln(h) + 2\sigma_\chi^2\right)^2}{8\sigma_\chi^2}\right) \tag{8}$$

for $h \geq 0$. The PDF of γ then yields

$$f_\gamma(\gamma) = \frac{1}{\sqrt{32\pi}\gamma\sigma_\chi}\exp\left(-\frac{\left(\ln(\gamma/\bar{\gamma}) + 4\sigma_\chi^2\right)^2}{32\sigma_\chi^2}\right) \tag{9}$$

which is also lognormally distributed, while the cumulative distribution function (CDF) results in a closed-form expression

$$F_\gamma(\gamma) = \frac{1}{2}\operatorname{erfc}\left[-\frac{\ln(\gamma/\bar{\gamma}) + 4\sigma_\chi^2}{\sqrt{32}\sigma_\chi}\right] \tag{10}$$

The value of $F_\gamma(\gamma)$ at $\gamma = \gamma_T$, $F_\gamma(\gamma_T)$, denotes the outage probability of the link.

C. Dependency of Channel Coefficients

Channel coefficients are basically correlated in time and space domains due to the movement of atmospheric eddies. Temporal correlativeness may affect optimal detection performance when a single-in single-out (SISO) system is investigated [9]. On the other hand, spatial correlativeness, needs to be considered when a spatial-based diversity system is going to be used to prove a better detection performance. Two important parameters coherence time and coherence length, in particular, represent the variation of the time-varying fading channel in time and space domain, respectively. In this work, we consider a multi-receiving system with only spatially correlated links.

Without loss of generality, the probability distribution of N identically distributed but correlated fading coefficients is a N-dimensional joint PDF. For the lognormal channel [3],

$$f_{\boldsymbol{H}}(h_1, h_2, \dots, h_N) = \frac{\exp\left(-\frac{1}{8}(\ln[\boldsymbol{H}] - 2\bar{\boldsymbol{\Psi}})\Sigma_\chi^{-1}(\ln[\boldsymbol{H}] - 2\bar{\boldsymbol{\Psi}})^T\right)}{2^N(2\pi)^{\frac{N}{2}}\left(\det\left[\Sigma_\chi\right]\right)^{\frac{1}{2}}\mathrm{P}[\boldsymbol{H}]} \tag{11}$$

where $\mathrm{P}[\boldsymbol{H}] \triangleq \prod_{n=1}^N h_n$ is the product function, $\boldsymbol{H}$ is the N-elements vector representing the channel coefficients:

$$\boldsymbol{H} = \{h_n\}_{n=1}^N = [h_1, h_2, \dots, h_N]_{1\times N} \tag{12}$$

and $\bar{\boldsymbol{\Psi}}$ is the average vector defined by

$$\bar{\boldsymbol{\Psi}} \triangleq [-\sigma_\chi^2, -\sigma_\chi^2, \dots, -\sigma_\chi^2]_{1\times N} \tag{13}$$

if the paths are identically faded. Here, we assume $\bar{h}_i = 1$ for $i = 1, \dots, N$ and Σ_χ is the covariance matrix

$$\Sigma_\chi = \begin{bmatrix} \sigma_\chi^2 & C_{1,2} & \cdots & C_{1,N} \\ C_{2,1} & \sigma_\chi^2 & \cdots & C_{2,N} \\ \vdots & \vdots & \ddots & \vdots \\ C_{N,1} & C_{N,2} & \cdots & \sigma_\chi^2 \end{bmatrix}_{N\times N} \tag{14}$$

where $C_{i,j}$ is the mutual covariance function between the log-amplitudes χ_i and χ_j of any two fading coefficients h_i and h_j for any two receivers i and j in Fig. 1. Note that $C_{i,j} = C_{j,i}$ due to symmetry property of correlation. The correlation coefficient is defined as $\rho_{i,j} \triangleq C_{i,j}/\sigma_\chi^2$, $0 \leq \rho_{i,j} \leq 1$. Due to the property of marginal PDF of a correlated Gaussian RV [10, example 12.2], it is drawn that the marginal PDF of h_n becomes

$$f_{h_n}(h) = \underbrace{\int_0^\infty \int_0^\infty \dots \int_0^\infty}_{N-1} f_{\hbar}(h_1, h_2, \dots, h_N) \underbrace{dh_1 \dots dh_j \dots dh_N}_{N-1; j\neq n}$$
$$= \frac{1}{\sqrt{8\pi}h_n\sigma_\chi}\exp\left(-\frac{\left(\ln(h_n) + 2\sigma_\chi^2\right)^2}{8\sigma_\chi^2}\right) \tag{15}$$

which is still a lognormal distribution given by (8). Since we assumed that channel coefficients $\{h_n\}_{n=1}^N$ are mutually correlated, the vector of SNR described by $\boldsymbol{\Gamma} \triangleq \{\gamma_n\}_{n=1}^N = \{h_n^2\bar{\gamma}_n\}_{n=1}^N$, has lognormaly correlated elements as well. In this case, the identically distributed joint PDF of SNR is

$$f_{\boldsymbol{\Gamma}}(\gamma_1, \gamma_2, \dots, \gamma_N) \tag{16}$$
$$= \frac{\exp\left(-\frac{1}{32}(\ln[\boldsymbol{\Gamma}] - \ln[\bar{\boldsymbol{\Gamma}}] - 4\bar{\boldsymbol{\Psi}})\Sigma_\chi^{-1}(\ln[\boldsymbol{\Gamma}] - \ln[\bar{\boldsymbol{\Gamma}}] - 4\bar{\boldsymbol{\Psi}})^T\right)}{4^N(2\pi)^{\frac{N}{2}}\left(\det\left[\Sigma_\chi\right]\right)^{\frac{1}{2}}\mathrm{P}[\boldsymbol{\Gamma}]}$$

where $\mathrm{P}[\boldsymbol{\Gamma}] \triangleq \prod_{n=1}^N \gamma_n$ is the product function of γ_n, and $\bar{\boldsymbol{\Gamma}} \triangleq \{\bar{\gamma}_n\}_{n=1}^N$ is the mean vector of SNR.

III. Selection Combining Approaches

In this section authors statistically depict two selection-combining schemes with detection characterization. Both follow similar selection strategy commonly based on the highest received SNR. Although this causes some estimation error, performance loss is negligible because it uses only branch selection and is not used for detection purposes. A review on the SC with availability of CSI is presented next.

The spatial diversity analyses for turbulence-induced FSO channels when CSI is known at the receiver side are investigated in the literature, including [2], [4], [8]. For such a SIMO system using SC technique, branch $n_{\max}$ is selected as

[1] - Even known as Rytov variance/parameter.

[2] - Can be considered also as the average power of the received signal.

the n where $h_{n_{\max}} = \max\{h_1, h_2, \ldots, h_N\}$. In this case, the detection threshold is simply designed as

$$I_{D,\,With-CSI} = \frac{\sigma_0 (I_0 + 2P_t R h_{n_{\max}}) + \sigma_1 I_0}{\sigma_0 + \sigma_1} \tag{17}$$

B. SC with Branch Balance

In the literature it is common to assume a spatially designed diversity system with identically distributed fading channels on balanced receiving branches. This concept is shown in Fig. 1. The "Compare & Select" block chooses the highest SNR to effectively maximize system performance. Practically, selection is based on SNR measurement during a short period of time, known as *short term* SNR, where resultant SNR $\gamma_{n_{\max}} \triangleq \max\{\gamma_1, \gamma_2, \ldots, \gamma_N\}$ is selected and $n_{\max}$ is where $\gamma_n = h_n^2 \bar{\gamma}_n$ is maximized. We assume the receiver can ideally find the branch with best quality.

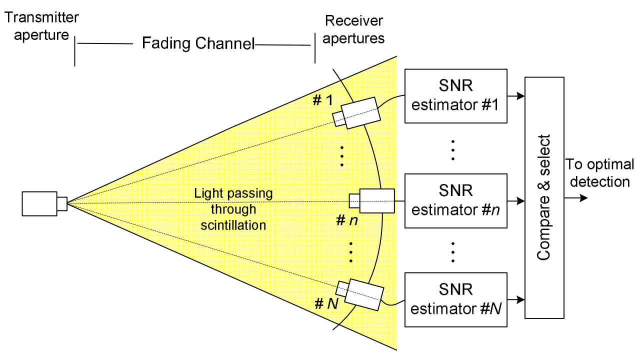

Fig. 1: A balanced multi-receiver structure model when receiving branches are physically and statistically balanced.

The PDF of γ_n in $\gamma_n = \bar{\gamma}_n h_n^2$ denotes as the marginal distribution of SNR given in (9). However, we want to extend the PDF to find $f_{\gamma_{n_{\max}}}(\gamma)$, $\gamma_{n_{\max}} = \max\{\gamma_1, \gamma_2, \ldots, \gamma_N\}$, where

$$\begin{aligned} f_{\gamma_{n_{\max}}}(\gamma) &= \underbrace{\int_0^{\gamma}\int_0^{\gamma}\cdots\int_0^{\gamma}}_{N-1} f_\Gamma(\gamma, \gamma_2, \ldots, \gamma_N)\, d\gamma_2 \ldots \gamma_N \\ &+ \underbrace{\int_0^{\gamma}\int_0^{\gamma}\cdots\int_0^{\gamma}}_{N-1} f_\Gamma(\gamma_1, \gamma, \ldots, \gamma_N)\, d\gamma_1 \ \ldots \gamma_N + \cdots \\ &+ \underbrace{\int_0^{\gamma}\int_0^{\gamma}\cdots\int_0^{\gamma}}_{N-1} f_\Gamma(\gamma_1, \gamma_2, \ldots, \gamma)\, d\gamma_1 d\gamma_2 \ldots \gamma_{N-1} \\ &= \sum_{i=1}^{N} \underbrace{\int_0^{\gamma}\int_0^{\gamma}\cdots\int_0^{\gamma}}_{N-1} f_\Gamma\Big(\gamma_1, \ldots, \underbrace{\gamma}_{i-th}, \ldots, \gamma_j, \ldots, \gamma_N\Big) \\ &\qquad \times \underbrace{d\gamma_1 \ldots d\gamma_j \ldots d\gamma_N}_{N-1;\, j\neq i} \end{aligned} \tag{18}$$

In (18), $f_\Gamma(\gamma_1, \gamma_2, \ldots, \gamma_N)$ is the joint probability distribution function given in equation (16). If fading links are identically distributed, (18) simplifies to

$$f_{\gamma_{n_{\max}}}(\gamma) = N \underbrace{\int_0^{\gamma}\int_0^{\gamma}\cdots\int_0^{\gamma}}_{N-1} f_\Gamma(\gamma, \gamma_2, \ldots, \gamma_N)\, \underbrace{d\gamma_2 d\gamma_3 \ldots d\gamma_N}_{N-1} \tag{19}$$

Now, the outage probability is characterized by

$$P_{out} = \int_0^{\gamma_T} f_{\gamma_{n_{\max}}}(\gamma)\, d\gamma \tag{20}$$

The BER performance of optimal detection can be inspected, as well. In order to develop a symbol-by-symbol detection in this case, the conditional probabilities are

$$p\big(r_{n_{\max}}|0\big) = \frac{1}{\sqrt{2\pi}\sigma_0} \exp\left(-\frac{\big(r_{n_{\max}} - I_0\big)^2}{2\sigma_0^2}\right) \tag{21}$$

where $r_{n_{\max}}$ is the received signal through branch $n_{\max}$. Similarly for the symbol '1'

$$\begin{aligned} p\big(r_{n_{\max}}|1\big) &= \frac{1}{\sqrt{2\pi}\sigma_1} \times \\ &\int_0^{\infty} f_{\gamma_{n_{\max}}}(\gamma) \exp\left(-\frac{\big(r_{n_{\max}} - I_0 - (\sigma_1 + \sigma_0)\sqrt{\gamma}\big)^2}{2\sigma_1^2}\right) d\gamma \end{aligned} \tag{22}$$

Finally, for equally likely transmitted symbols, the *average* BER of symbol-by-symbol detection becomes

$$\begin{aligned} BER_{S-by-S} &= \frac{1}{2}\int_{\Lambda(r_{n_{\max}})>1} p\big(r_{n_{\max}}|0\big)\, dr_{n_{\max}} \\ &+ \frac{1}{2}\int_{\Lambda(r_{n_{\max}})<1} p\big(r_{n_{\max}}|1\big)\, dr_{n_{\max}} \end{aligned} \tag{23}$$

where $\Lambda\big(r_{n_{\max}}\big) \triangleq p\big(r_{n_{\max}}|1\big)/p\big(r_{n_{\max}}|0\big)$.

C. SC with Branch Unbalance

The discussion on probability distribution of the resultant output SNR in the previous section is logically valid only when the links present identical short term SNRs (in Eq. (7)) with identically distributed fading branches. However, the most practical case becomes visible when the links are asymmetrically unbalanced, as shown in Fig. 2. The connected receivers obtain either different average SNRs or different fading strengths (i.e. σ_χ). Two applications for employing unbalanced spatial multi-receiving apertures for such links are the development of angular diversity and MANET [11].

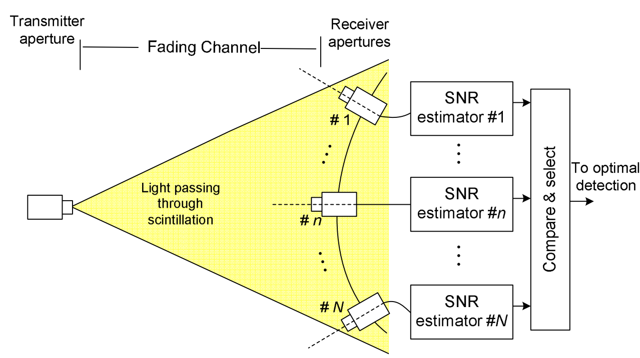

Fig. 2: An unbalanced multi-receiver structure model when receiving branches get different average SNRs due to angular misalignment.

Mathematically speaking, the instantaneous SNR is defined as

$$\gamma_n = \frac{4R^2 h_n^2 \alpha_n^2 P_t^2}{\big(\sigma_{1,n} + \sigma_{0,n}\big)^2} = h_n^2 \alpha_n^2 \bar{\gamma} \quad ; n = 1,2 \ldots, N \tag{24}$$

where $\bar{\gamma}_n$ is the average received signal with no fading defined in (6). In (24), α_n, $0 \le \alpha_n \le 1$, is the gain factor of receiver n due to misalignment or angular reception. In practical applications, e.g. angular diversity, noise powers $\sigma_{1,n}^2$ and $\sigma_{0,n}^2$ can be assumed constant at different apertures, but α_n differs for different receivers due to position fluctuation. If we assume α_n is deterministic, the probability of outage cannot be statistically evaluated. Accordingly, we can model $\{\alpha_n\}_{n=1}^N$ as independent unknown RVs with a given distribution of $f_{\alpha_1}(\alpha) = f_{\alpha_2}(\alpha) = \cdots = f_{\alpha_N}(\alpha) = f_\alpha(\alpha)$. In order to statistically derive the marginal PDF of γ_n, the PDFs of both h_n^2 and α_n^2 are needed. For the former, we can easily find the expression by using $h_n^2 = e^{4\chi}$,

$$f_{h_n^2}(h) = \frac{1}{\sqrt{32\pi} h \sigma_\chi} \exp\left(-\frac{\left(\ln(h) + 4\sigma_\chi^2\right)^2}{32\sigma_\chi^2}\right) \quad (25)$$

and for the joint distribution,

$$f_{h^2}(h_1, h_2, \dots, h_N) \quad (26)$$
$$= \frac{\exp\left(-\frac{1}{32}(\ln[\boldsymbol{H}] - 4\ln[\bar{\boldsymbol{H}}])\Sigma_\chi^{-1}(\ln[\boldsymbol{H}] - 4\ln[\bar{\boldsymbol{H}}])^T\right)}{4^N(2\pi)^{\frac{N}{2}}\left(\det\left[\Sigma_\chi\right]\right)^{\frac{1}{2}}\mathrm{P}[\boldsymbol{H}]}$$

while $f_{\alpha_n^2}(\alpha)$ is considered as the PDF of α_n^2. The only parameter depending on n is α_n, which is different for different apertures. The PDF of α_n^2 becomes

$$f_{\alpha_n^2}(\alpha) = \frac{1}{2\sqrt{\alpha}}\left[f_{\alpha_n}(\sqrt{\alpha}) + f_{\alpha_n}(-\sqrt{\alpha})\right] \quad (27)$$

Since h_n and α_n can be confidently assumed uncorrelated, using the help of [12, ex. 7] as the PDF of the product of RVs,

$$f_{\gamma_n}(\gamma_n) = \int_0^1 \frac{1}{u} f_{h_n^2}\left(\frac{\gamma_n}{u}\right) f_{\alpha_n^2}(u)\, du \quad (28)$$

where $f_{\gamma_n}(\gamma_n)$ is the marginal PDF of channel fading given by (9). We extend it to the joint representation

$$f_\Gamma(\gamma_1, \gamma_2, \dots, \gamma_N) = \int_0^1 \frac{1}{u} f_{h^2}\left(\frac{\gamma_1}{u}, \frac{\gamma_2}{u}, \dots, \frac{\gamma_N}{u}\right) f_{\alpha_n^2}(u)\, du \quad (29)$$

To this end, the PDF of $\gamma_{n_{\max}} = \max\{\gamma_1, \gamma_2, \dots, \gamma_N\}$ is derived similarly from (19), while the outage probability and BER can be computed using (20) and (23), respectively.

D. SNR Estimation

Estimating the value of short term received SNR is needed to employ multi-receiving aperture based on SC. Such estimated SNR is used throughout the selection process, but not for detection purposes. Any individual receiver n has a different value of average SNR, which can be easily estimated by means of pilot symbol assisted modulation (PSAM). As shown in Fig. 3, N_p known symbols '1' and '0' are periodically inserted into the information slots at the transmitter side. Using (4), the SNR can basically be estimated as [13]

$$\hat{\gamma}_n \triangleq \left(\frac{\hat{I}_{1,n} - \hat{I}_{0,n}}{\hat{\sigma}_{1,n} + \hat{\sigma}_{0,n}}\right)^2 \quad (30)$$

where $\hat{I}_{1,n}, \hat{I}_{0,n}, \hat{\sigma}_{1,n}$ and $\hat{\sigma}_{0,n}$ are respectively estimated values of where I_1, I_0, σ_1 and σ_0 for receiver n. If $N_p \ll \tau_c/T_b$, the estimator in (30) will provide $\hat{\gamma}_n = h_n^2\bar{\gamma}_n$, due to high temporal correlation. Such assumption means that if $\tau_c \gg T_b$, i.e. the variation to the fading intensities is relatively slow, h_n can be assumed constant over a short given observation interval. Although $\hat{\gamma}_n$ in this case still includes the fading coefficient, SC combiner maximizes the performance by choosing the greatest one: $\hat{\gamma}_{n_{\max}} = \max\{\hat{\gamma}_1, \hat{\gamma}_2, \dots, \hat{\gamma}_n\}$.

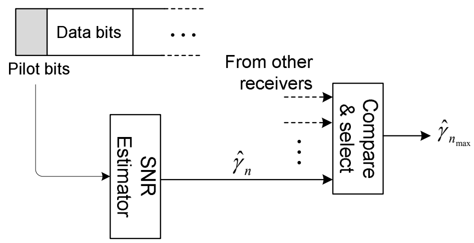

Fig. 3: Simple SNR estimator for finding $\hat{\gamma}_{n_{\max}}$ when $\tau_c \gg T_b$ is satisfied.

IV. Simulation Analysis

Numerical analysis is carried out by computing the integral expressions in BER and outage probabilities. Deriving exact closed-form expressions for the probabilities of the cases $N > 2$, is extremely complex, especially when the channels are mutually correlated. Alternatively, we can measure the BER and outage probability by sending OOK symbols through a fading channel and detecting the received symbols using a metric like ML. Using a symbol-by-symbol detection method, the error and outage occurrences can then be measured by applying the decision metric. For any resultant signal $r_{n_{\max}}$, computation of $p(r_{n_{\max}}|0)$ for the ML at the receiver can be easily accomplished, while an N–dimensional numerical integration for $p(r_{n_{\max}}|1)$ is required. We suggest using a thresholding-based detection approach [14] to significantly reduce such computational load.

The simulations assume equal noise powers for symbols '0' and '1', $\sigma_0 = \sigma_1$ where the mean of the noise is set to I_0=0.2. When needed, definition $\bar{\gamma}$ in (6) is used as the *average received SNR* in the performance plots. The values of correlation coefficient are assumed as $\{\rho_{i,j}\}_{i,j=1,i\neq j}^N = \rho$ where $\rho_{i,j} = 1$ for $i = j$.

Fig. 4 shows the effect of correlation on the BER of an SC with branch balance when a dual-branch receiver $N = 2$. Dependency among fading coefficients degrades combining efficiency. For instance, a performance loss of more than 3dB is realized when the correlation coefficient increases to $\rho = 0.9$. The performance of SC combining technique when compared with EGC is plotted in Fig. 5. As mentioned earlier, branch balance performance, in terms of BER, will increase when an SC combining technique is chosen over EGC. For branch unbalance configuration, shown in Fig. 6, EGC functionality is not acceptable due to significant performance loss. In this case, SC provides superior performance.

As a final comparison, Fig. 7 provides BER performance of undertaken detection schemes. We have assumed identically distributed gain factors $\{\alpha_n\}_{n=1}^N$ with uniform distribution changing between 0 and 1. When compared with a EGC technique, the performance of SC is superior when assuming branches are unbalanced. A more practical case is achieved when a more precise representation of distribution for $\{\alpha_n\}_{n=1}^N$ is found.

V. Conclusions

When obtaining instantaneous CSI, the estimation error causes performance loss in both combining and detection processes. Such error appears even if the channel has a relatively long coherence time. This paper has considered a

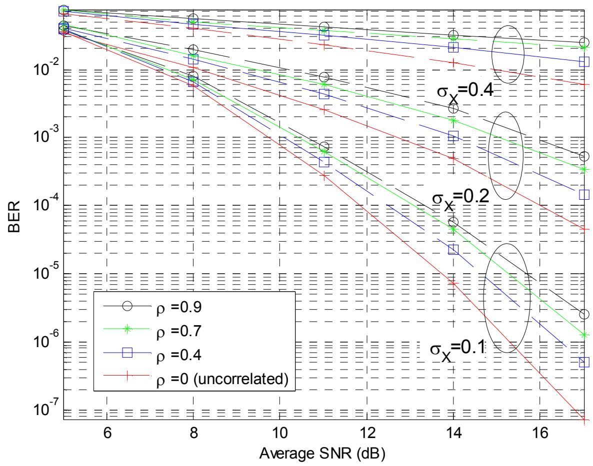

Fig. 4: The effect of correlation for a $N = 2$ receiving structure with branch balance and SC combining.

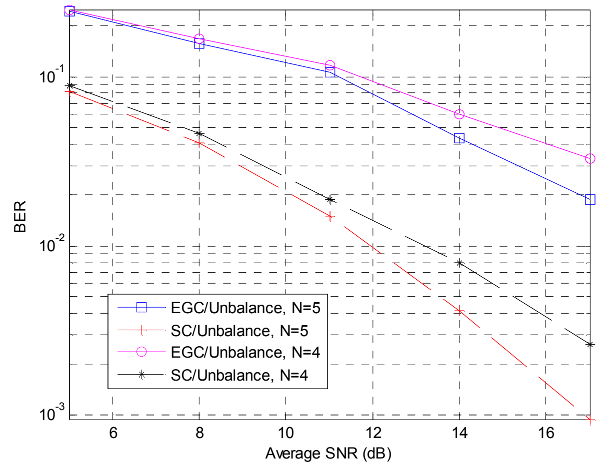

Fig. 6: BER of aperture unbalance for SC and EGC. $\sigma_\chi = 0.2$, $\rho = 0$.

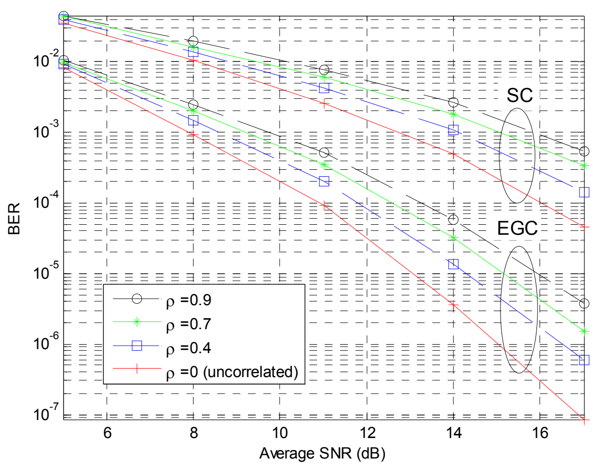

Fig. 5: Performance of SC compared to EGC for a $N = 2$ receiving structure with branch balance. $\sigma_\chi = 0.2$

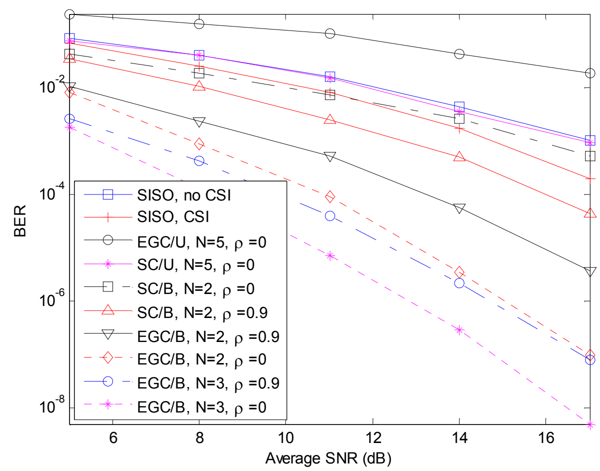

Fig.7: A comparison of BER for several combining cases. $\sigma_\chi = 0.2$.

multi-receiving design without perfect instantaneous CSI knowledge where apertures are either balanced or unbalanced. An SNR estimation was performed to facilitate branch selection with the highest short term SNR obtained through SC combining. Unlike OC-based systems and because the value of estimated SNR is not directly involved in the combining process or detection purposes, estimation error does not remarkably degrade performance. Simulation demonstrates that regular EGC technique provides a superior BER performance when branches are balanced. It was observed that SC provides superior performance in the event of unbalance, which is more common in practice.

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