Center for Optical Technologies

LEHIGH UNIVERSITY · PENNSTATE 1855 · Northampton Community College · Ben Franklin Technology PArtners Northeastern Pennsylvania · Lehigh Carbon COMMUNITY COLLEGE

Scaling Laws for FSO Communications (II): Multiple Receivers

PI: Jing Li (Tiffany)* Co-PI: Jennifer Ricklin^ζ Research Assistant: Meng Yu*

** Lehigh University,* ^ζ *Army Research Laboratory*

Introduction

• FSOC systems with **multiple transmitters** and a single receiver can be effectively viewed as single transmitter and a single receiver systems operating on a better FSOC channel.

• **How about systems with multiple receivers?**

Consider:

- single transmitter (**SLMD**) and multiple transmitters (**MLMD**)
- the availability of Channel State Information at the receiver
- different combining schemes

Assumption:

- log-normal fading channel model

SLMD FSOC Systems

Possible signal combining strategies: MRC & EGC

Optimal Combining (OC)

- Aims to minimize BER → Optimal combining
- Requires CSI at the decoder
- The outputs of the receive apertures are combined to yield the decision metric

$$2\sum_{n=1}^{N} I_n r_n \underset{off}{\overset{on}{\gtrless}} \sum_{n=1}^{N} I_n^2$$

The bit error rate performance of **SLMD MRC** implementation is

MRC BER: (with CSI)

$$P_e = \int_{\mathbf{x}} f_{\mathbf{x}}(\mathbf{x})\, Q\left(\frac{\eta I_0}{2\sigma_v}\sqrt{\sum_{n=1}^{N} e^{4x_n}}\right) d\mathbf{x} \quad \leftarrow \text{vector integral}$$

Equal gain combining (EGC)

- Decoder CSI not needed for operation
- Simply adds the receiver branches – Low complexity but suboptimal

The bit error rate performance of **SLMD EGC** implementation is

EGC BER: (with CSI)

$$P_e = \int_{\mathbf{x}} f_{\mathbf{x}}(\mathbf{x})\, Q\left(\frac{\eta I_0}{2\sqrt{N}\sigma_v}\sum_{n=1}^{N} e^{2x_n}\right) d\mathbf{x} \quad \leftarrow \text{vector integral}$$

$$\approx \int_{-\infty}^{\infty} N\left(x, -\frac{2\sigma_x^2}{N}, \frac{4\sigma_x^2}{N}\right) Q\left(\frac{\eta\sqrt{N} I_0 e^{x}}{2\sigma_v}\right) dx \quad \leftarrow \text{scalar integral}$$

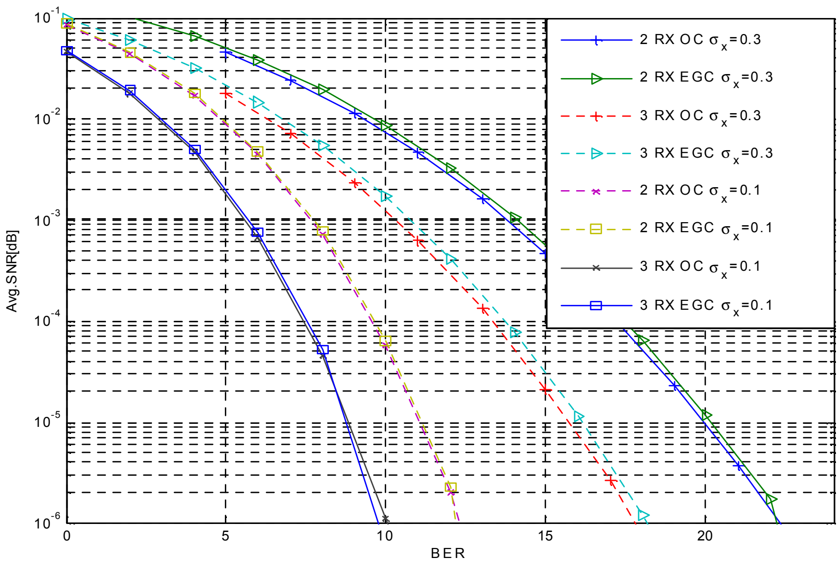

Fig. 1. BER of SLMD using MRC (exact BER) and EGC (approximated BER).

Observations from Figure 1

• EGC performs only slightly worse than MRC

→ Will use EGC when evaluating MIMO systems

• The introduced approximation is simple and good

→ Will use approximation to reduce the computational complexity

MLMD FSOC Systems

When CSI is available at the decoder:

The **BER** performance of **MLMD EGC** implementation is

BER: (EGC)

$$P_e = \int_{\mathbf{x}} f_{\mathbf{x}}(\mathbf{x})\, Q\left(\frac{\eta I_0}{2M\sigma_v}\sum_{m=1}^{M}\sum_{n=1}^{N} e^{2x_{mn}}\right) d\mathbf{x} \quad \leftarrow \text{vector integral}$$

$$\approx \int_{-\infty}^{\infty} N\left(x, \log MN - \frac{2\sigma_x^2}{MN}, \frac{4\sigma_x^2}{MN}\right) Q\left(\frac{\eta I_0 e^{x}}{2M\sqrt{N}\sigma_v}\right) dx \quad \leftarrow \text{scalar integral}$$

$$= \int_{-\infty}^{\infty} N\left(x, -\frac{2\sigma_x^2}{MN}, \frac{4\sigma_x^2}{MN}\right) Q\left(\frac{\eta\sqrt{N} I_0 e^{x}}{2\sigma_v}\right) dx$$

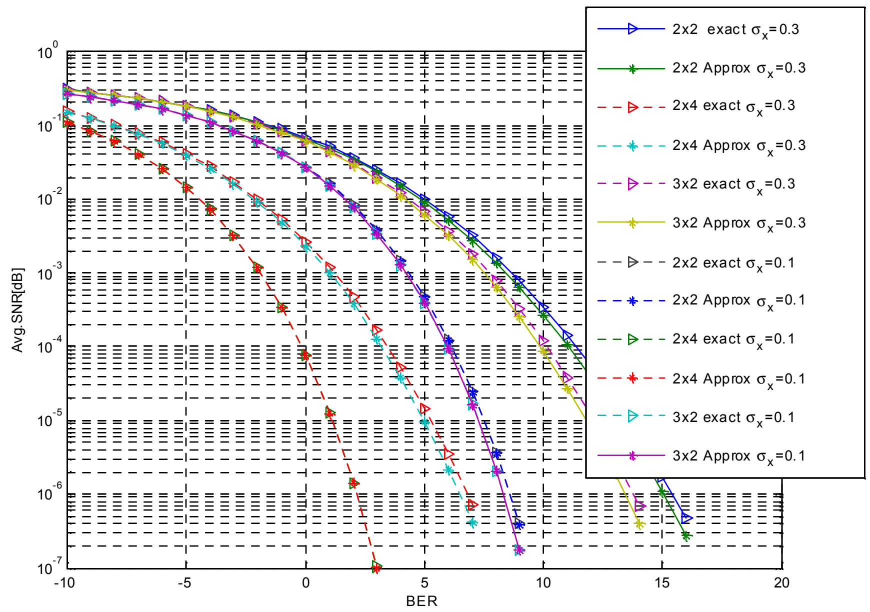

Fig. 2. BER of MLMD systems with CSI using EGC

When CSI is NOT available at the decoder:

The **likelihood function** of **MLMD Maximum Likelihood** decoder is

$$\Lambda(r) = \int_{\mathbf{x}} f_{\mathbf{x}}(\mathbf{x}) \exp\left\{-\frac{1}{N_0}\left[\left(r - \eta I_0 \frac{1}{M}\sum_{n=1}^{M}\sum_{n=1}^{N} e^{2x_{mn}}\right)^2 - r^2\right]\right\} d\mathbf{x} \quad \leftarrow \text{vector integral}$$

$$\approx \int_{-\infty}^{\infty} N\left(x, -\frac{2\sigma_x^2}{MN}, \frac{4\sigma_x^2}{MN}\right) \exp\left(-\frac{\left(r - \eta I_0 N e^{x}\right)^2 - r^2}{N_0}\right) dx \quad \leftarrow \text{scalar integral}$$

BER is evaluated by integrating the tailing probability of the likelihood function.

→ Closed-form BER expressions not available…

Conclusion

• FSO links with transmit and/or receive diversity (MLSD, SLMD, MLMD systems) can be efficiently represented by single-laser single-detector (SLSD) systems with appropriate scaling in the channel variance.

• The performance difference between EGC and MRC is minor

→ EGC may be desired for its low complexity.