# Lehigh University
# Center for Optical Technologies

# Efficient Forward Error Correction Coding for Free-Space Optical Communications

PI: Tiffany Jing Li*, Co-PI: Jennifer Ricklin$^{\zeta}$, Graduate Assistant: Meng Yu*

* *Lehigh University,* $^{\zeta}$ *Army Research Laboratory*

## Motivation of the Work

- Reed-Solomon (RS) codes: very simple and fast, can have a very high code rate, no error floors ➔ suitable for high-data-rate free space optics
- Goal: evaluate the performance of RS codes in out-door long-distance free-space optical communication (FSOC) systems

## System Model

**Log-Normal Scintillation Channels:** Optical signals are dominated by atmospheric turbulence. The channel can be modeled as log-normal fading.

$$y_k = I_k x_k + n_k$$

$$f_I(z) = \frac{1}{2z\sigma_z\sqrt{2\pi}}\exp\left(-\frac{(\ln z)^2}{8\sigma_z^2}\right)$$

**Temporal Correlation:** real FSOC channels also experience temporal correlation. Here we use Markov model to describe it.

$$I_{k+1} = I_k^{\sqrt{1-\alpha}} J_k^{\sqrt{\alpha}}, \quad k = 1, 2, \cdots, n$$

$\alpha \in [0,1]$, correlation factor

$J_k$ -- i.i.d. As $I_k$

## Bit-by-bit Detection

**Bit-by-bit detector** detect bit s as $\hat{s} = \arg\max_s P(r|s)$

The hard decision threshold $\theta$ is chosen at the value when log-likelihood function

$$\Lambda(r) = \log\frac{P(r|1)}{P(r|0)} = 0$$

The raw data bit error rate is $P_b = (P(err|off) + P(err|on))/2$, where

$$P(err|off) = P(1|0) = \int_{\Lambda(\theta)>0} p(r|0)dr = Q\left(\frac{2\theta}{N_0}\right)$$

$$P(err|on) = P(0|1) = \int_{\Lambda(\theta)<0} p(r|1)dr$$

$$= \frac{1}{2\pi\sigma_z\sqrt{2N_0}}\int_{\Lambda(\theta)<0}\left(\frac{1}{x}e^{-\frac{\ln x}{8\sigma_z^2}}\right)*\left(e^{-\frac{x^2}{N_0}}\right)dx$$

The error probability of transmitting ``on'' signals is consistently larger than that of transmitting ``off'' signals regardless of SNR values and turbulence strengths

➔this result has never been reported

➔possible smarter treatment ? e.g. adjusted (shifted) decision threshold

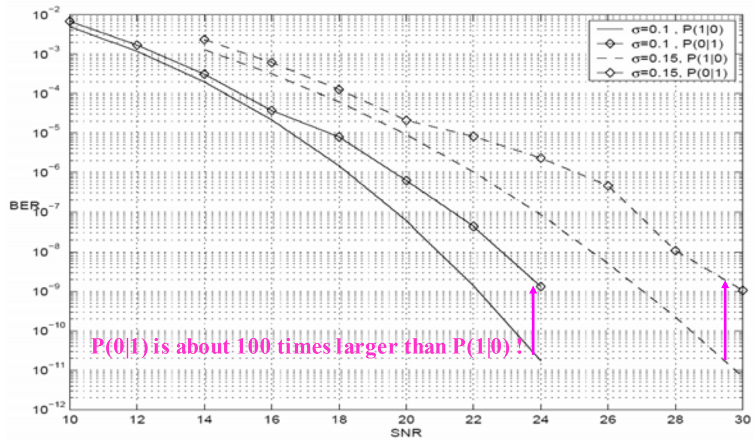


Figure 1. Raw data error probability caused by "on" and "off" signals.

## Performance Analysis

For an *(n,k)* RS code capable of correcting *t* symbol errors where each symbol consists of *s* consecutive bits, the word error rate (or block error rate) is lower bounded by

$$P_{bound} = P(bit\ err\,|\,word\ \ in\ err)P_w \gtrsim \frac{tk}{n^2}P_w$$

$$P_w = 1 - \sum_{i=0}^{t}\binom{n}{i}P_s^i(1-P_s)^{n-i}$$

$$P_s = 1 - (1-P_b)^s$$

$P_b$ -- raw data bit error rate

$P_w$ -- Symbol error rate

$P_s$ -- word error rate

## Simulation Result

***(255, 239)* RS code**: codeword length 2040 bits, information block size1912 bits, 7% of overhead, Berlekamp-Massey hard-decision decoding.

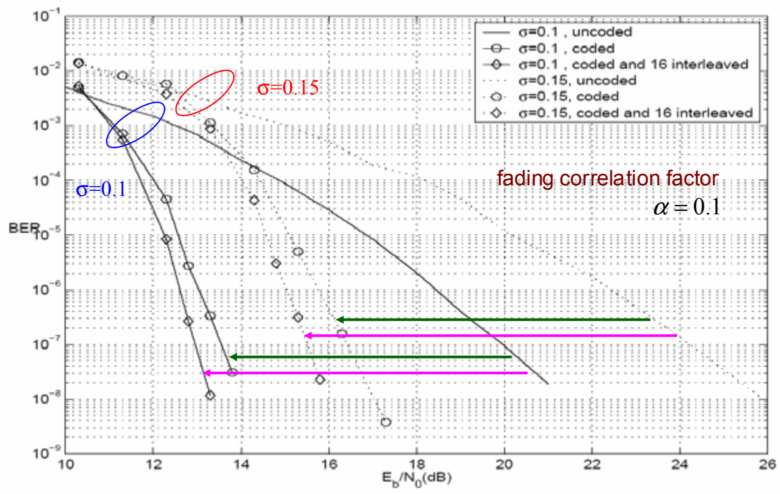


Figure 2. Fast fading FSOC channels with different turbulence levels

➔ Coding gain of a single RS code over uncoded systems

➔ Coding gain of a 16-way interleaved RS code over uncoded systems

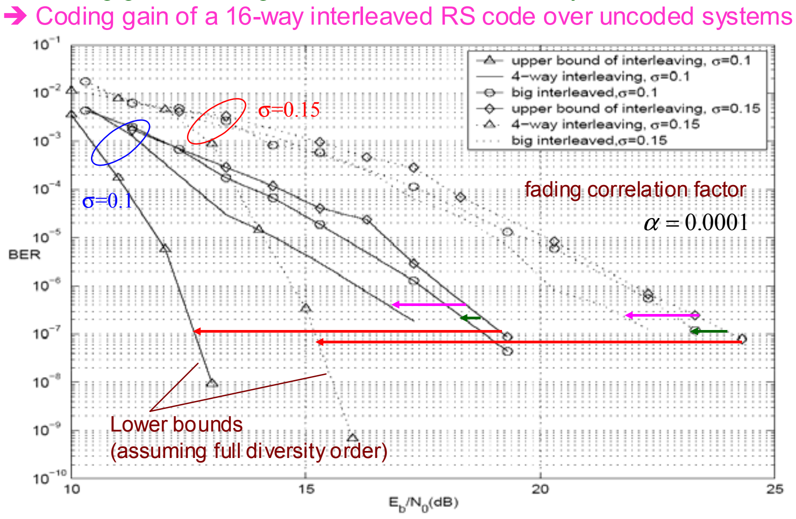


Figure 3. Slow fading FSOC channels with different turbulence levels

➔Coding gain of a single RS code over uncoded systems

➔Coding gain of a 16-way interleaved RS code over uncoded systems

➔Potential coding gain: requires a larger interleaver and longer delay

## Conclusion

- RS code can provide noticeable coding gain with very little overhead (7%).
- Interleaving technique can provide diversity gain.

[1] Meng Yu, Jing (Tiffany) Li and Jennifer Ricklin, "Efficient Forward Error Correction Coding for Free-Space Optical Communications," to appear, *Proceeding of the conference on Free-Space Laser Communications IV, Optical Science and Technology, SPIE's 49th Annual Meeting*, Denver, CO, Aug. 2004.