

Opportunistic Cooperation for FSO Links Aided by Decode and Forward Relay

Michael (Qunfeng) He^{*}, Zhengyuan Xu⁺

***Department of Electrical Engineering
University of California, Riverside**

**+Department of Electronic Engineering
Tsinghua University, China**

Outline

- **Motivations and Setup**
- **Problem Formulation and Signal Model**
- **Channel Model**
- **Link Outage Analysis: DT, dDF and oDF**
- **Numerical Results**

Motivations and Setup

■ Motivations

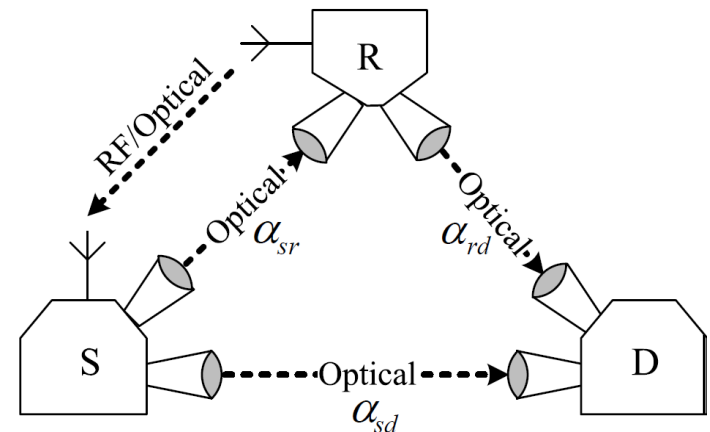
- FSO link in IR wavelength is challenged by turbulence
- Traditional approaches: time and spatial diversity
- Recent advances: user cooperation in Poisson domain [Karimi 09], [Abou-Rjeily 11]
 - Our work: Gaussian noise assumption, opportunistic relay [Safari 08]

■ System setup

- DT phase: S-R & S-D
- DF phase: S-D or R-D (conditional)
- R-S: CSI feedback link

■ Categories

- Non-cooperation (Direct transmission)
- Deterministic cooperation
- Opportunistic cooperation



A three-way FSO network for opportunistic cooperation.

Problem Formulation and Signal Model

■ Problem formulation: outage probability of a FSO link

- Characterize the outage over fading channel
- Given SNR, the instantaneous rate $R = \log_2(1 + SNR)$
- Probabilistic event s.t. R meets required R_0

$$P_{out}(R_0) = P_r\{\log_2(1 + \Gamma) < R_0\} = P_r\{\Gamma < \Gamma_{th}\} \quad (1)$$

■ SNR model

- Consider binary PPM,

$$r_{NC} = \begin{pmatrix} r_{NC}^s \\ r_{NC}^n \end{pmatrix} = \begin{pmatrix} (P_s g_{sd} + RT_s P_b) + nsd \\ RT_s P_b + nnd \end{pmatrix} \quad (2)$$

- Electrical SNR

$$\Gamma = \frac{(\mu^s - \mu^n)^2}{\sigma_n^2} \quad \Gamma_{NC} = \frac{(P_s g_{sd})^2}{\sigma_n^2} \quad (3)$$

Channel Model

- Channel coefficient, described by [Safari 08] $g = \alpha^2 L(d)$

(4)

- Path loss: $L(d) = \frac{A_r}{(\Omega d)^2} \exp(-\xi d)$

(5)

- Turbulence model, weak turbulence: log-normal distribution

$$f(\alpha) = \frac{1}{\sqrt{2\pi\sigma_x^2}\alpha} \exp\left(-\frac{\ln\alpha - \mu_x}{2\sigma_x^2}\right) \quad \sigma_x^2(d) = 0.124k^{\frac{7}{6}}C_n^2 d^{\frac{11}{6}} \quad (6)$$

- Outage probability of a DT FSO link

- Plugging SNR and fading models

$$P_{out,DT} = P_r\{\Gamma < \Gamma_{th}\} = \Pr\left\{\alpha_{sd}^2 < \sqrt{\frac{\Gamma_{th}\sigma_n^2}{(LsdP_s)^2}}\right\} \quad (7)$$

$$= Q\left(\frac{\ln(K_{sd,th,DT}) - 2\sigma_x^2(dsd)}{2\sigma_x(dsd)}\right)$$

A Deterministic Cooperative FSO Link

- Deterministic cooperation: dDF
 - Parallel links in nature: S-D and S-R-D
 - Outage happens when both paths fail
- Outage of dDF:
 - Assume the same signal expressions

$$P_{out, dDF} = P_{out, sd, DT} P_{out, srd, DF} \quad (8)$$

$$\text{where, } P_{out, srd, DF} = 1 - (1 - P_{out, sr})(1 - P_{out, rd}) \quad (9)$$

$$P_{out, dDF} = Q\left(\frac{\ln(K_{sd, th, dDF}) - 2\sigma_x^2(dsd)}{2\sigma_x(dsd)}\right) \cdot \left\{ 1 - \left[1 - Q\left(\frac{\ln(K_{sr, th, dDF}) - 2\sigma_x^2(dsr)}{2\sigma_x(dsr)}\right) \right] \left[1 - Q\left(\frac{\ln(K_{rd, th, dDF}) - 2\sigma_x^2(drd)}{2\sigma_x(drd)}\right) \right] \right\} \quad (10)$$

An Opportunistic Cooperative FSO Link

- Outage probability for opportunistic cooperation of FSO links

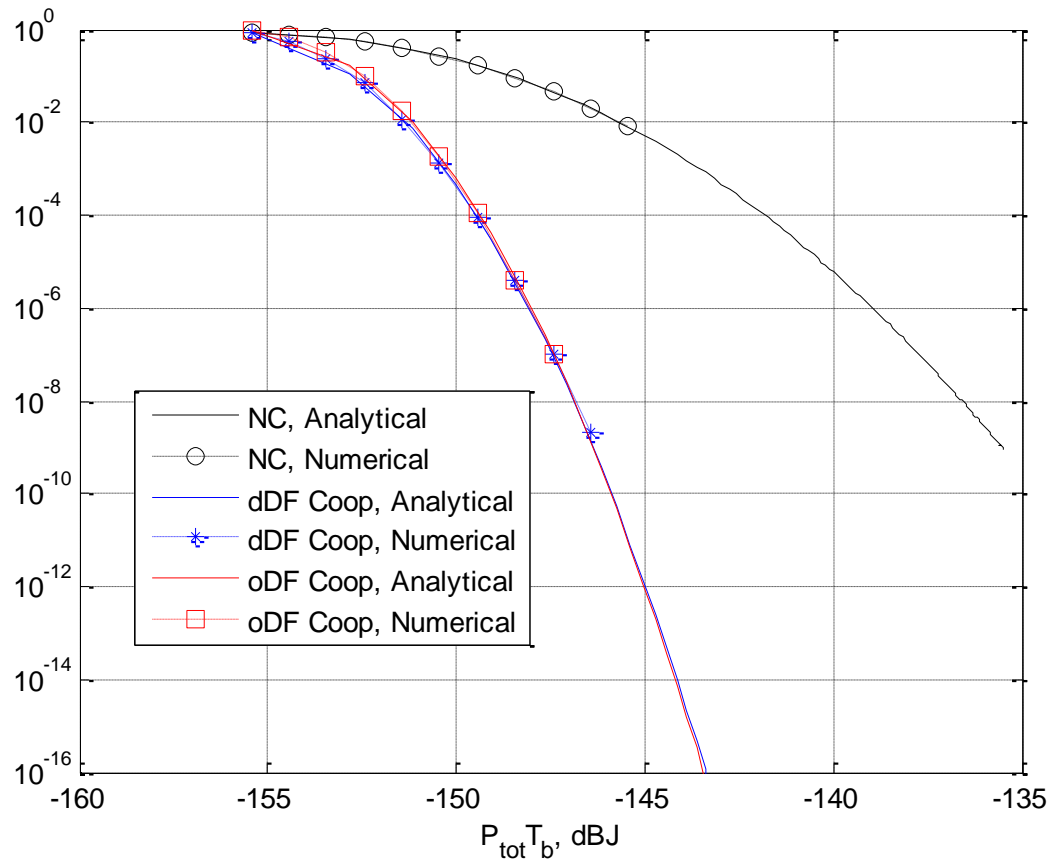
$$P_{out, oDF} = P_{out, sr} P_{out, oDF - DT} + (1 - P_{out, sr}) P_{out, oDF - DF} \quad (11)$$

- Each component can be retrieved from prev. analysis
 - Obtaining the signal representation
 - Developing the SNR
 - Applying the outage probability expression

- Numerical study
 - Direct computation on analytical outage probability equations
 - Monte-Carlo simulation on SNR and numerical outage probability
 - Compare above results to validate the analysis

Numerical Results (1)

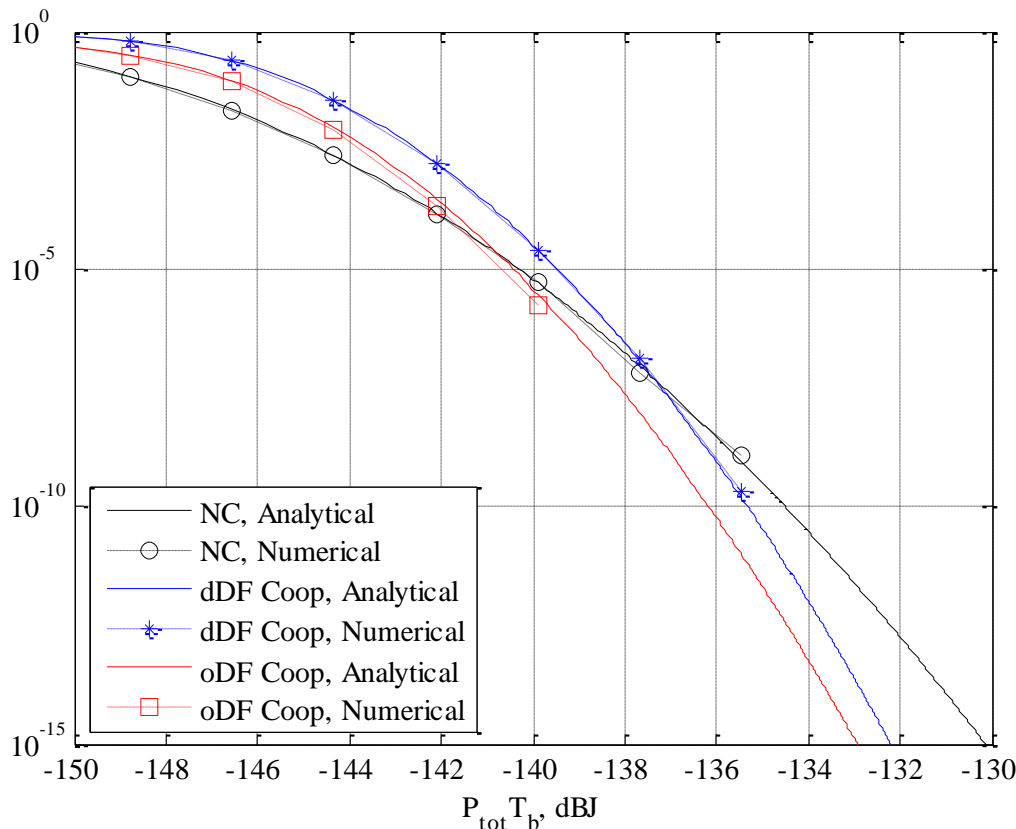
- A special case where relay lies on the middle point of S-D
 - To verify cooperation does improve the link
 - Contrast the analytical form against Monte-Carlo simulation



Outage performance of opportunistic FSO system aided by DF relay, $d_{sr} = d_{rd} = 500\text{m}$, $d_{sd} = 1000\text{m}$.

Numerical Results (2)

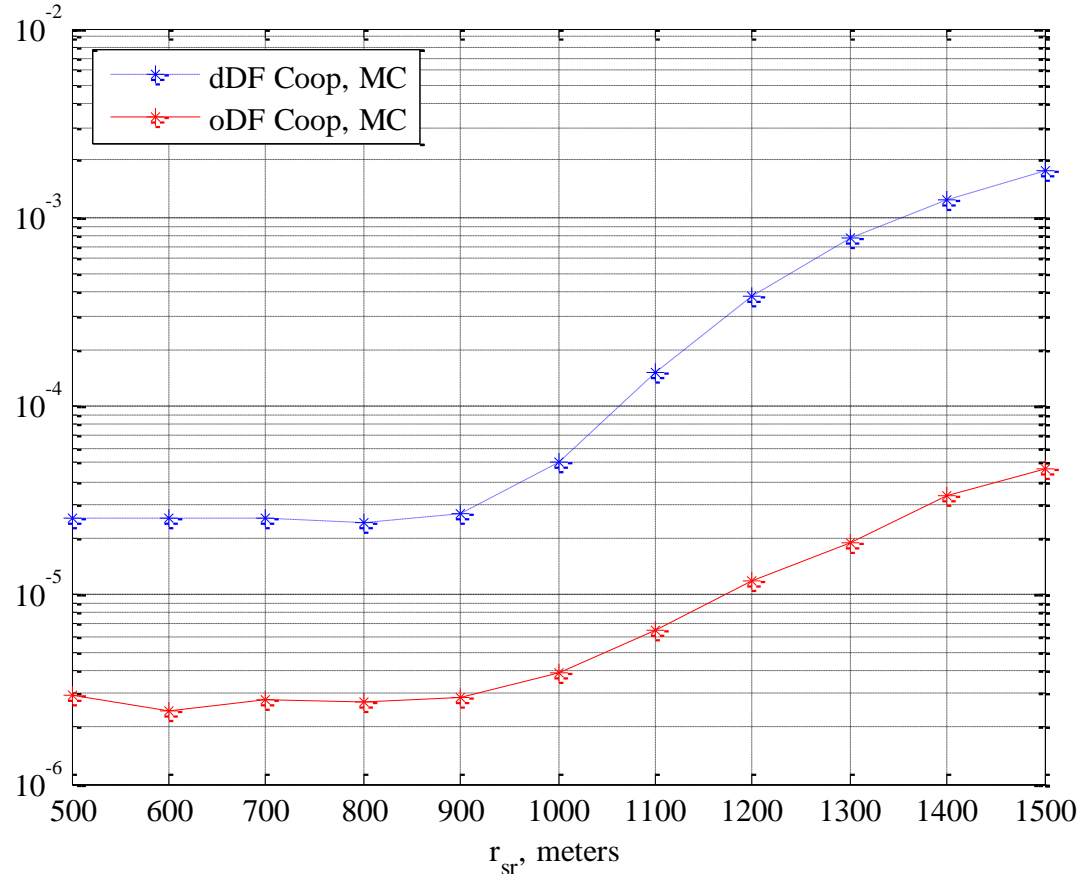
- Increasing the S-R separation, equivalent to downgrading the S-R quality
 - Opportunistic cooperation excels deterministic version in high power regime
 - Opportunistic cooperation has wider adaptability
 - There exists a range within which cooperation is applicable



Outage performance of opportunistic FSO system aided by DF relay, $d_{sr} = d_{rd} = d_{sd} = 1000\text{m}$.

Numerical Results (3)

- Checking the outage performance on multiple separations of S-R



Outage performance of opportunistic cooperation vs. S-R link distance, $d_{rd} = d_{sd} = 1000\text{m}$.

Thank you!