# Achievable Rate and Optimal Signaling for an Optical Wireless Decode-and-Forward Relaying Channel

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# Outline

- Background
- System model
- Symbol number filling algorithm (SNFA)
- Simulation results
- Conclusion

# Background

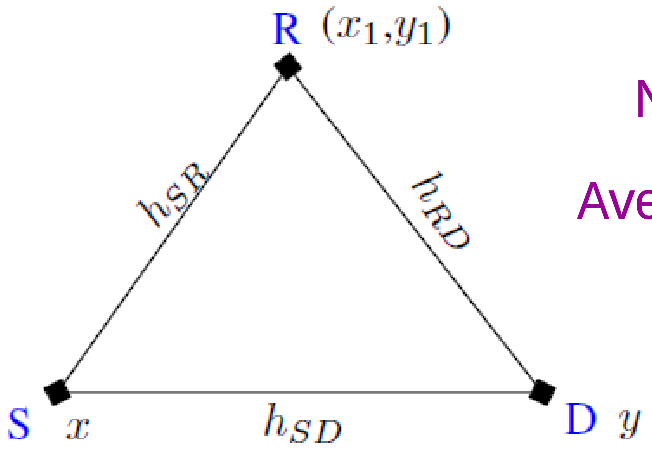
- **Optical wireless communication (OWC)**
  - Large transmission bandwidth
  - Unregulated spectrum of light
  - Free of electromagnetic radiation
- **Challenges for outdoor OWC**
  - Atmospheric turbulence-induced fading
  - Misalignment impairments
- **Relay-assisted OWC (RA-OWC)**
  - Introduce cooperative diversity
  - Extend the coverage
  - Improve link robustness

# Background

- **Capacity related research in RA-OWC**
  - Capacity bounds and relay placement (1-D)
  - Input independent Gaussian noise
  - Continuous input distributions
- **Our contributions**
  - Input-dependent Gaussian shot noise
  - Discrete input distributions
  - SNFA and optimal signaling
  - Relay placement over a 2-D plane

# System model

- **Intensity modulation and direct detection (IM-DD)**




Nonnegative constraint $X \geq 0, X_1 \geq 0$

Average power constraint $\mathbb{E}[X] \leq \varepsilon_1, \mathbb{E}[X_1] \leq \varepsilon_2$

Peak power constraint $\mathbb{P}[X > A_1] = 0$
$\mathbb{P}[X_1 > A_2] = 0$

- **Received signals**

Relay node $Y_1 = h_{SR}X + \sqrt{h_{SR}X}Z_{1d} + Z_1$

Destination node $Y = h_{SD}X + h_{RD}X_1 + \sqrt{h_{SD}X + h_{RD}X_1}Z_{2d} + Z_2$

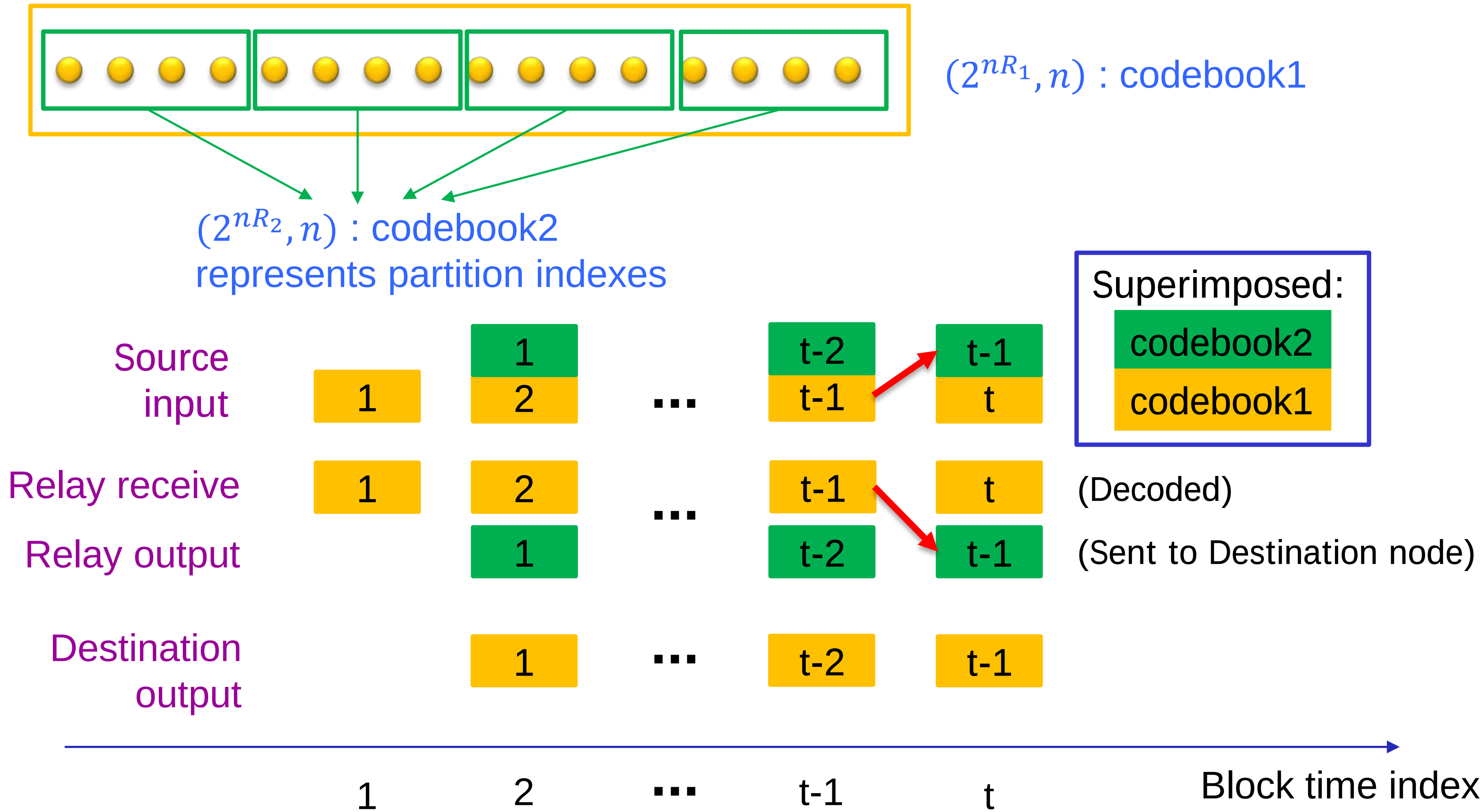
- **Mutually independent Gaussian noises**

Input independent $Z_1 \sim \mathcal{N}(0, \sigma_1^2)$ $Z_2 \sim \mathcal{N}(0, \sigma_2^2)$

Input dependent $Z_{1d} \sim \mathcal{N}(0, \varsigma_1^2\sigma_1^2)$ $Z_{2d} \sim \mathcal{N}(0, \varsigma_2^2\sigma_2^2)$

# System model

## Full duplex decode and forward (DF) relay protocol



# System model

- **Capacity with DF relaying protocol**

$$C = \sup_{p(x,x_1)} \min(I(X,X_1;Y), I(X;Y_1|X_1)) \quad (*)$$

  - Assumption: physical degradedness

$$p(y|x,x_1,y_1) = p(y|x_1,y_1)$$

- **Challenges in RA-OWC**
  - Channels are not generally physically degraded
  - Conditions for physical degradedness are hard to obtain
  - No closed form of (*)
- **Alternatives**
  - Achievable rate maximization problem
  - (*) is an achievable rate
  - Discrete input distribution

# Symbol number filling algorithm

## Rate maximization problem

$$R = \max_{\mathbf{Z}} \min(I(X, X_1; Y), I(X; Y_1 | X_1))$$

- Subject to: probability axioms, nonnegative inputs, average and peak power constraints

## Compact vector form

$$\mathbf{Z} = [\mathbf{p}, \mathbf{q}, \mathbf{q}_1]$$

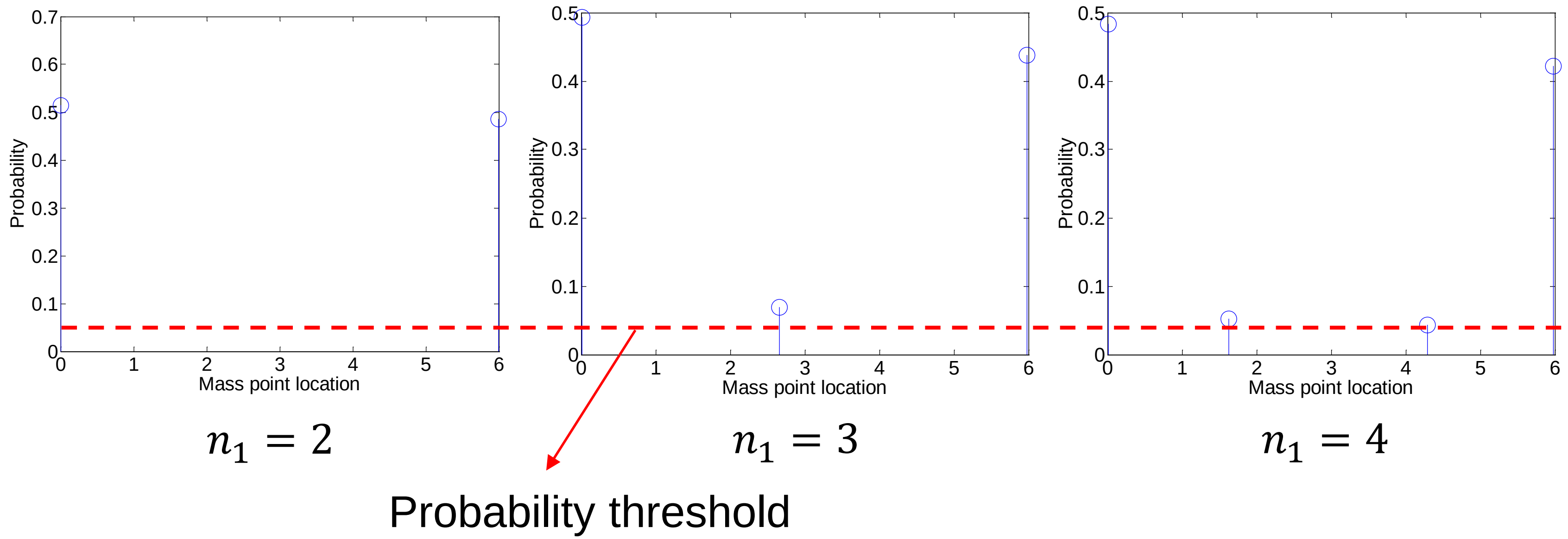
$\mathbf{p}$: vectorized joint input distribution
$\mathbf{q}$: $n_1$ constellation points for the source
$\mathbf{q}_1$: $n_2$ constellation points for the relay

- $n_1$ and $n_2$ are fixed
- Solved by standard heuristic optimization approach

# Symbol number filling algorithm

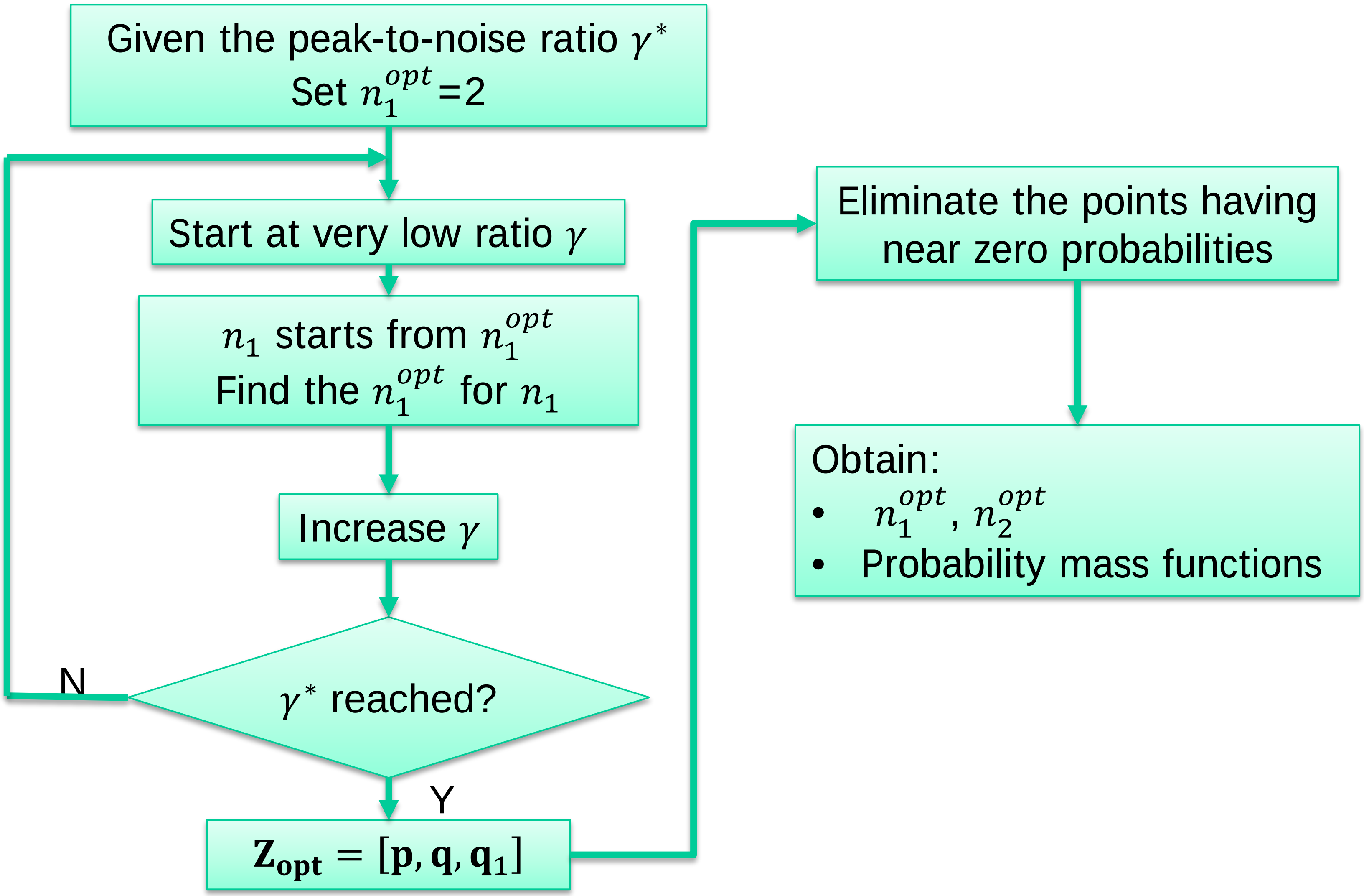
- **Determine optimal constellation sizes**
  - Near zero probability occurs when the number of mass points is greater than the optimal

For a given peak-to-noise ratio:



# Symbol number filling algorithm

## ■ SNFA diagram

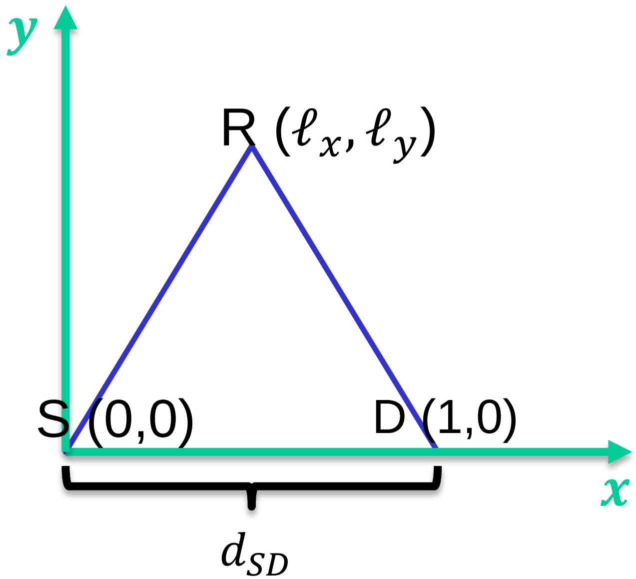


# Simulation results

## Simulation assumptions

- Channel gains are proportional to $1/d^2$ ($d$ is the distance)
- Node S and R have the same ***input constraints***
- Node S and D have the same ***noise variances***

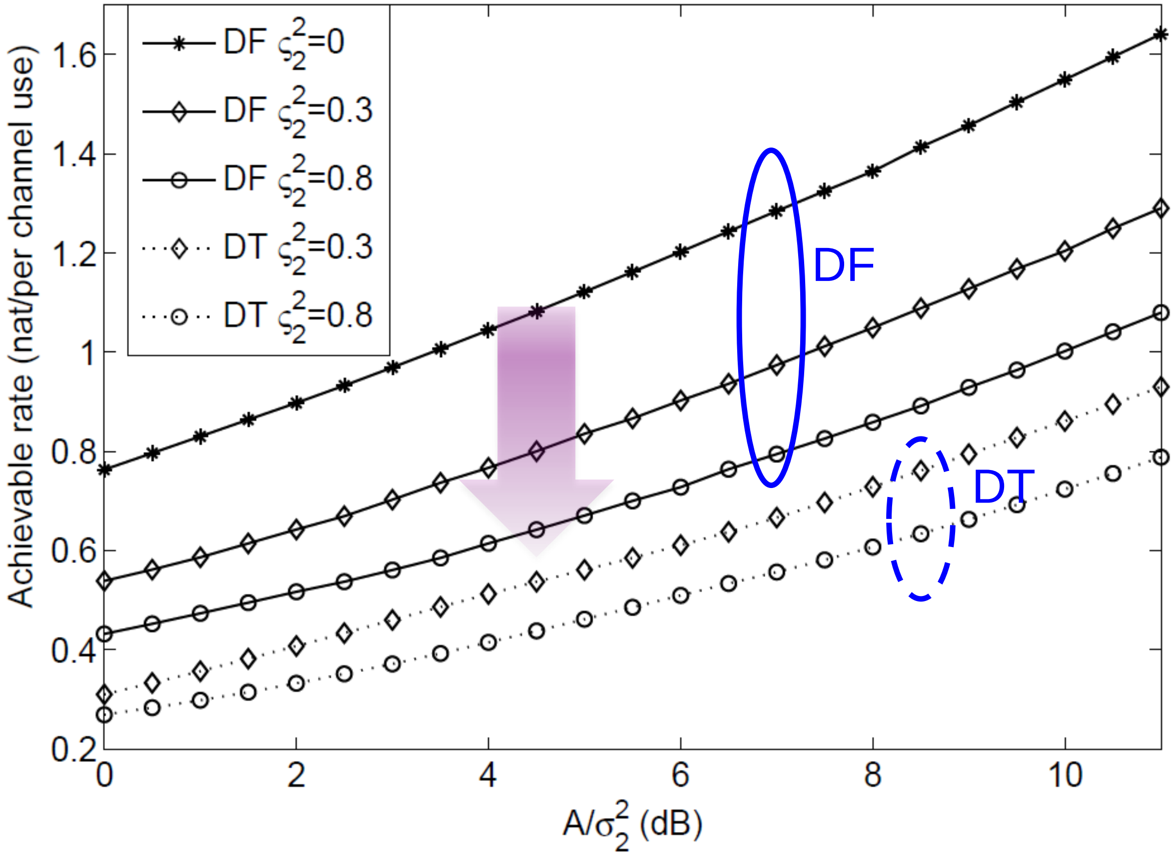
## Simulation settings




All distances are normalized to $d_{SD}$

# Simulation results

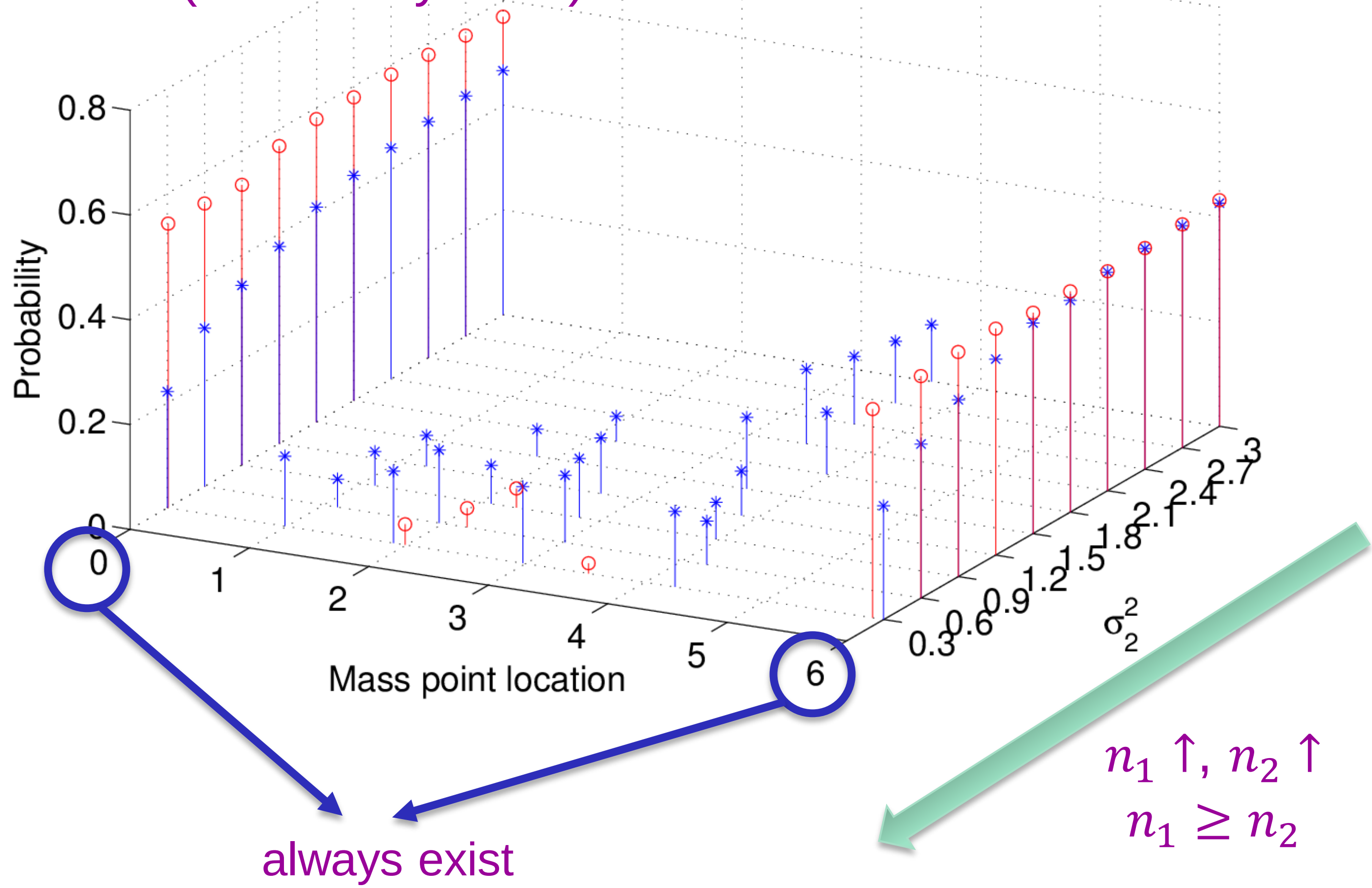
## ■ Achievable rates for various input-dependent noises




$\ell_x = 0.5$
$\ell_y = 0.5$

# Simulation results

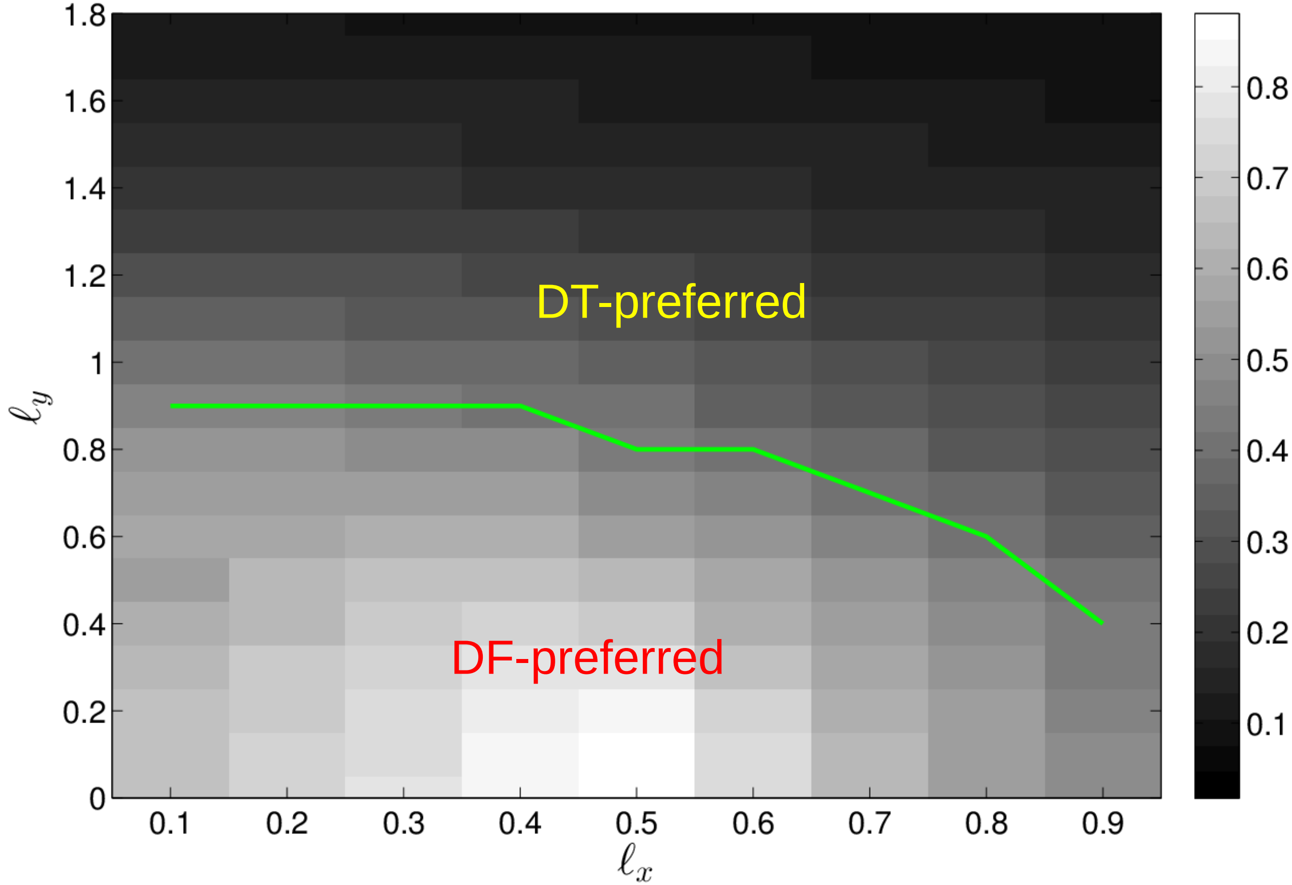
- **Constellation points for:**
  - relay (marked by circles)
  - source (marked by stars)




$\ell_x = 0.5$
$\ell_y = 0.5$
$A = 6$

# Simulation results

## ■ Relay placement over two-dimensional plane




- ➢ Lighter color: larger rate
- ➢ Darker color: lower rate

# Conclusion

- A more realistic RA-OWC model is studied
- Optimal signaling & achievable rate via SNFA
- DF relaying generally outperforms DT
- DF-preferred relay position given on 2-D plane

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# Thank you!

## Q&A