Systems, AI/ML Augmented U-LiFi

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Contents

Underwater LiFi (U-LiFi): an introduction

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- Why do we need LiFi underwater? **Sufficient spectrum, low transmission attenuation**

Environmental monitoring

Energy exploration

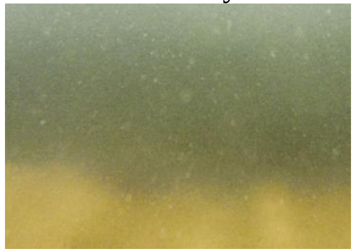
Underwater culture

UUV

Submarine

Diver

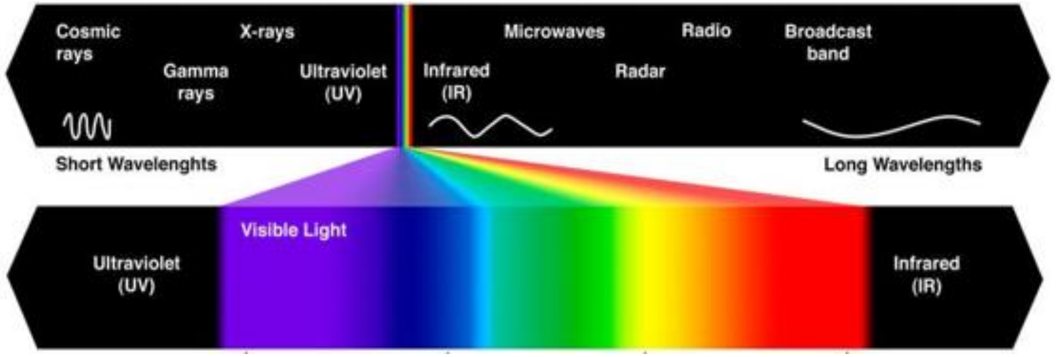
Turbidity

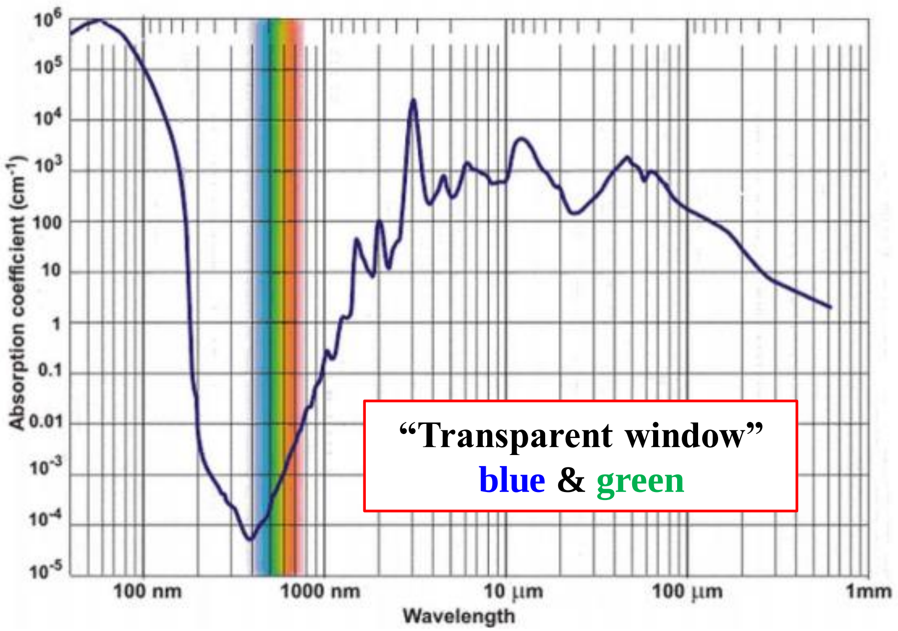


Wave

Air bubbles

Reliable, high-speed and low-latency communication is required in dynamic underwater environments





Harald Haas, et al., "What is LiFi?", Journal of Lightwave Technology, 2016.

Z. Zeng, et al., "A survey of underwater optical wireless communications," IEEE Communications Surveys & Tutorials, 2017.

- A comparison of underwater wireless communication technologies:

Acoustic	RF	U-LiFi
Low data rate (kbps)	High data rate (Mbps)	Ultra-high data rate (Gbps)
Large latency	Low latency	Low latency
Long transmission distance	Short transmission distance	Moderate transmission distance
Costly and energy consuming transceivers	Costly and energy consuming transceivers	Low cost and small transceivers
Low security	Low security	High security

C. Gussen, et al., “A survey of underwater wireless communication technologies,” Journal of Communication and Information Systems, 2016.
Z. Zeng, et al., “A survey of underwater optical wireless communications,” IEEE Communications Surveys & Tutorials, 2017.

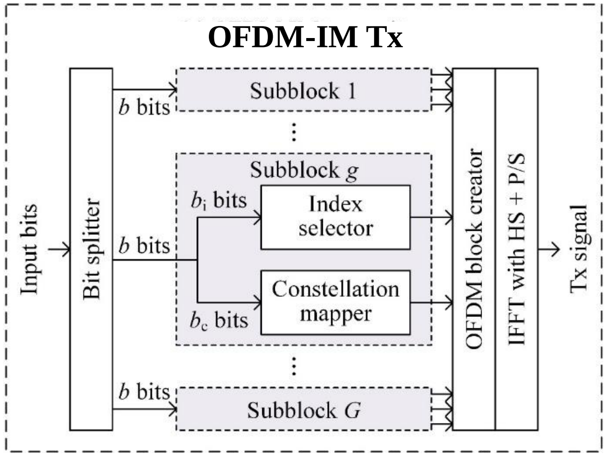
Reliable U-LiFi systems: index modulation & recognition

- Motivation: enable reliable U-LiFi via flexible index modulation

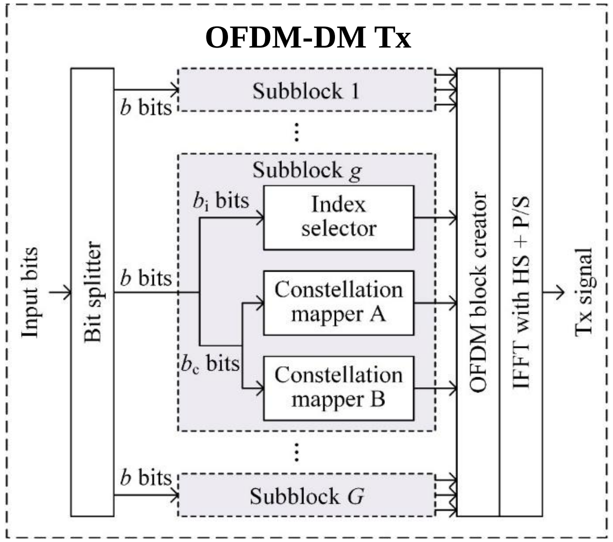
- Our approach

1. Flexible OFDM index modulation (OFDM-IM) for dynamic U-LiFi channels
2. Deep learning-aided modulation recognition (constellation & index)

Single-mode



Dual-mode



OFDM-IM with N=4 and k=2

Index bits	Index set for $\mathcal{M}$	Subblocks
0 0	[1, 2]	$[S_i, S_j, 0, 0]$
0 1	[2, 3]	$[0, S_i, S_j, 0]$
1 1	[3, 4]	$[0, 0, S_i, S_j]$
1 0	[1, 4]	$[S_i, 0, 0, S_j]$

$$SE_{\mathrm{IM}} = \frac{\lfloor \log_2(C(N,k)) \rfloor + k\log_2(M)}{N}$$

OFDM-DM with N=4 and k=2

Index bits	Index set for $\mathcal{M}_{\mathrm{A}}$	Index set for $\mathcal{M}_{\mathrm{B}}$	Subblocks
0 0	[1, 2]	[3, 4]	$[S_i^{\mathrm{A}}, S_j^{\mathrm{A}}, S_i^{\mathrm{B}}, S_j^{\mathrm{B}}]$
0 1	[2, 3]	[1, 4]	$[S_i^{\mathrm{B}}, S_i^{\mathrm{A}}, S_j^{\mathrm{A}}, S_j^{\mathrm{B}}]$
1 1	[3, 4]	[1, 2]	$[S_i^{\mathrm{B}}, S_j^{\mathrm{B}}, S_i^{\mathrm{A}}, S_j^{\mathrm{A}}]$
1 0	[1, 4]	[2, 3]	$[S_i^{\mathrm{A}}, S_i^{\mathrm{B}}, S_j^{\mathrm{B}}, S_j^{\mathrm{A}}]$

$$SE_{\mathrm{DM}} = \frac{\lfloor \log_2(C(N,k)) \rfloor + k\log_2(M_{\mathrm{A}}) + (N-k)\log_2(M_{\mathrm{B}})}{N}$$

Modulation scheme	OFDM-IM	OFDM-DM
Spectral efficiency	Low	High
Power efficiency	High	Low
Application scenarios	Low-SNR scenarios	High-SNR scenarios

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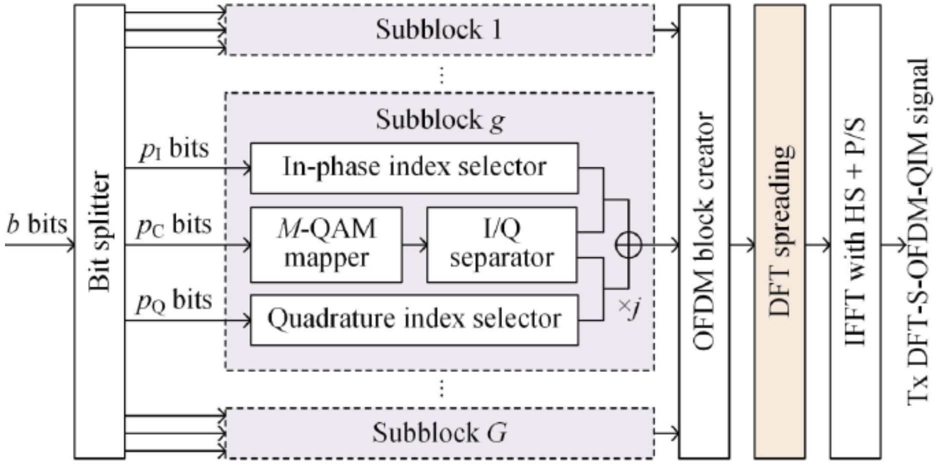
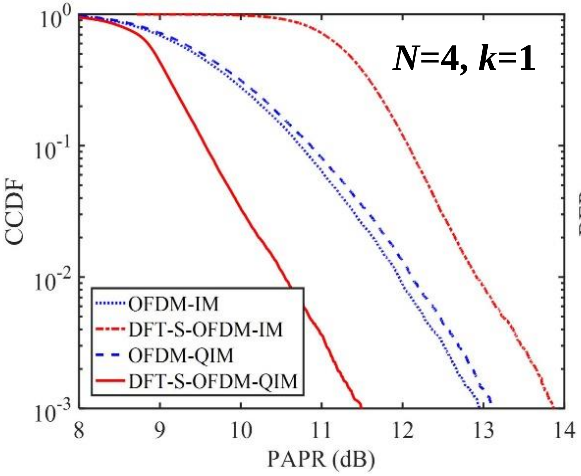
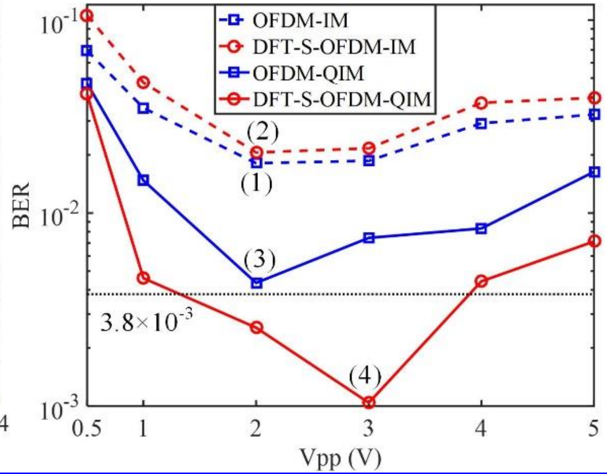
Flexible OFDM-IM for reliable U-LiFi systems

OFDM with quadrature index modulation (OFDM-QIM)

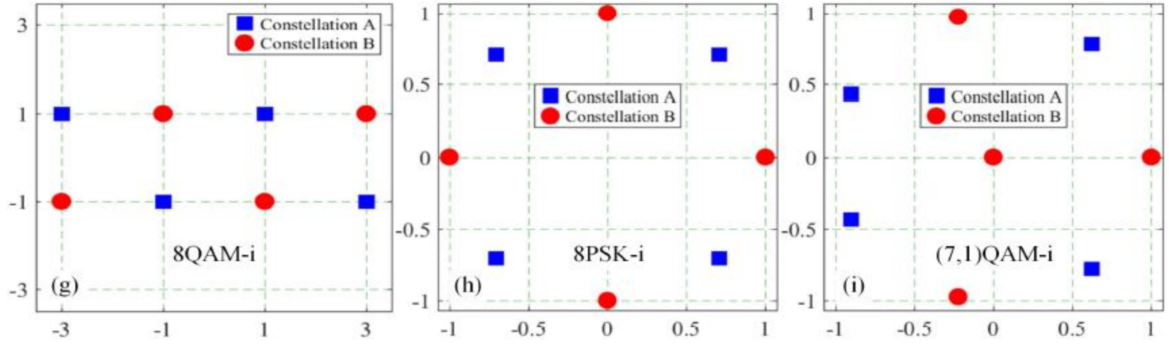


$$SE_{\mathrm{QIM}} = \frac{2\lfloor \log_2(C(N,k)) \rfloor + k\log_2(M)}{N}$$

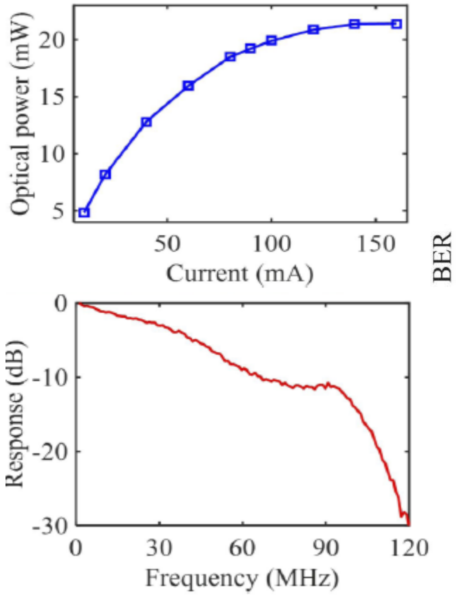


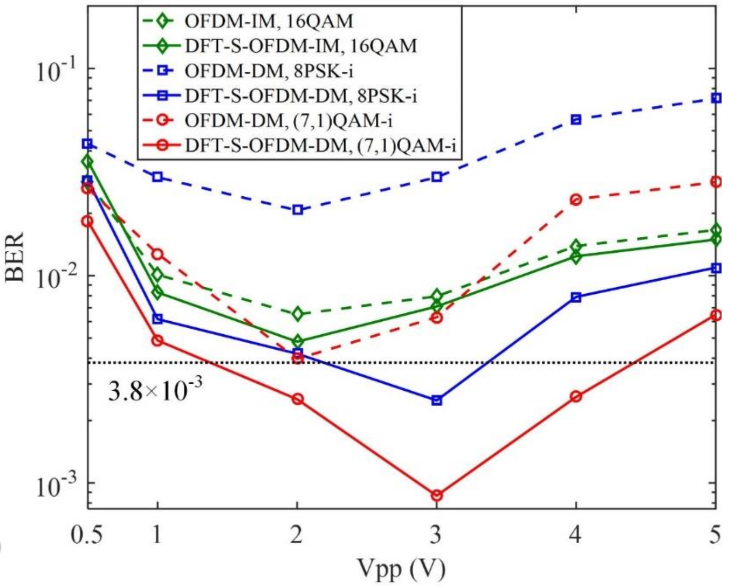


Constellation design for OFDM-DM

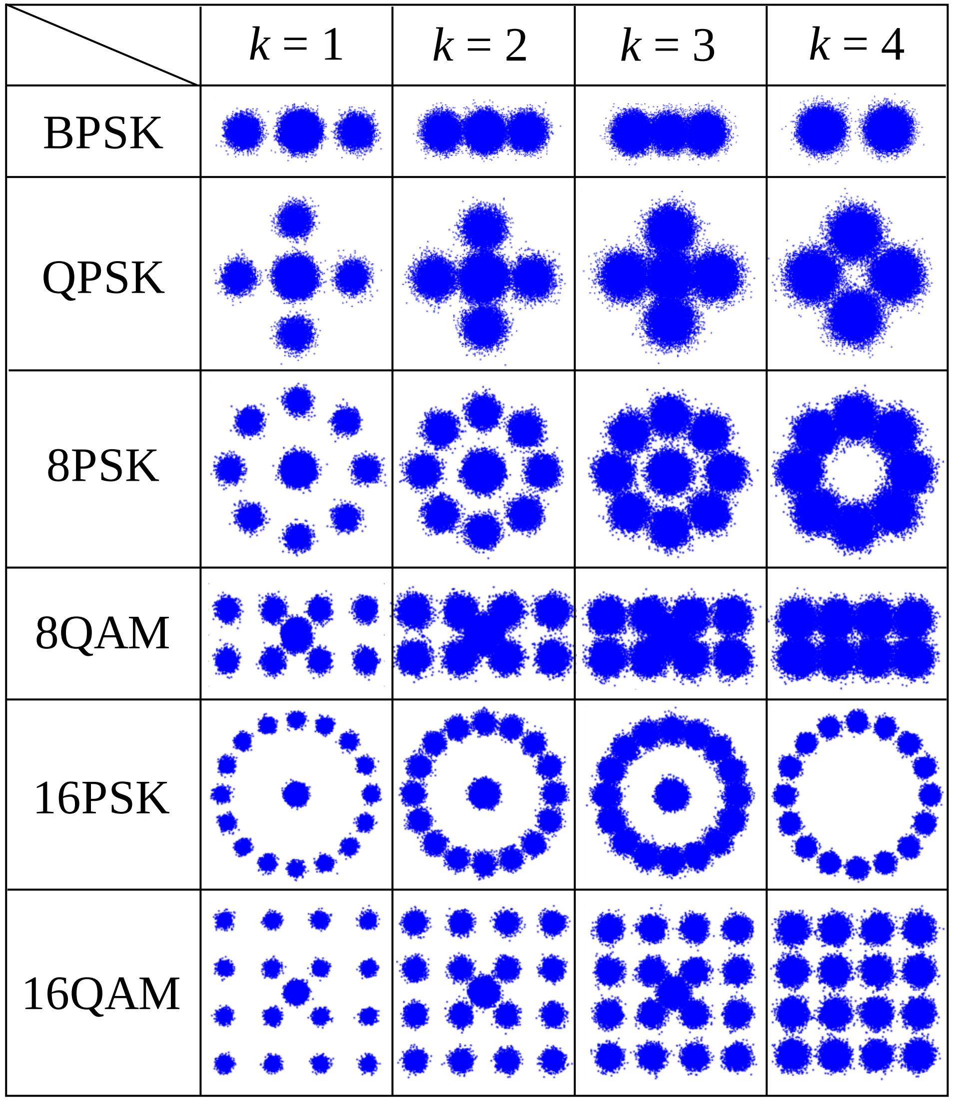


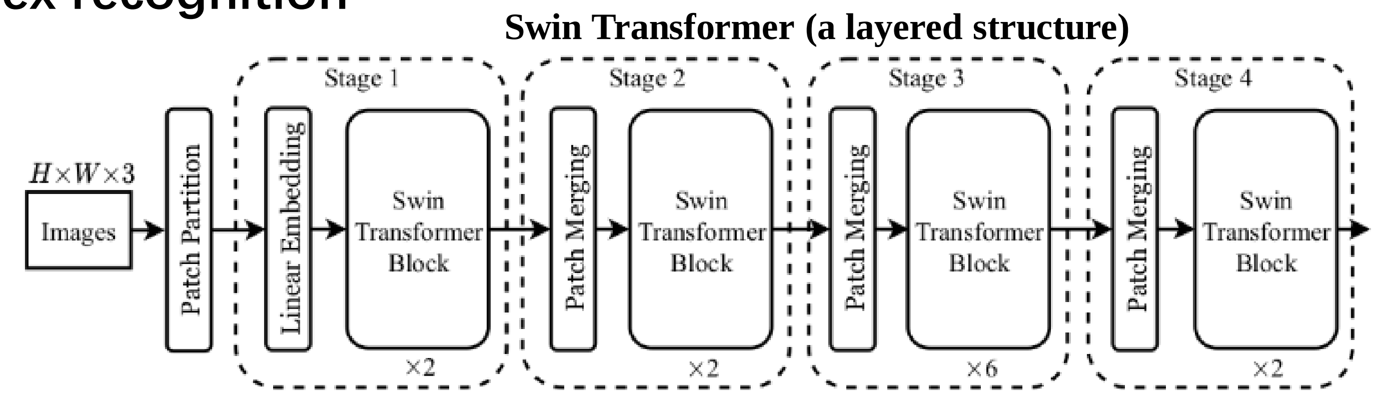
Interleaving-based constellation partitioning

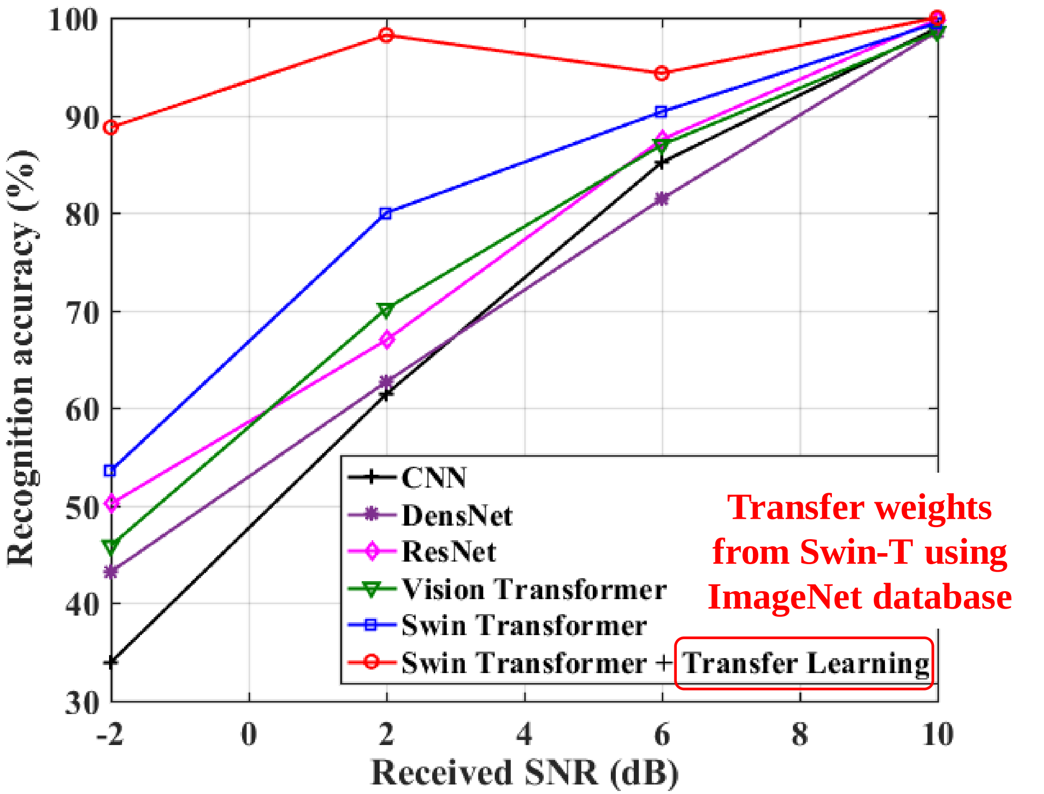




- **DL-aided joint constellation and index recognition**







Bandlimited U-LiFi systems: how much BW we can use?

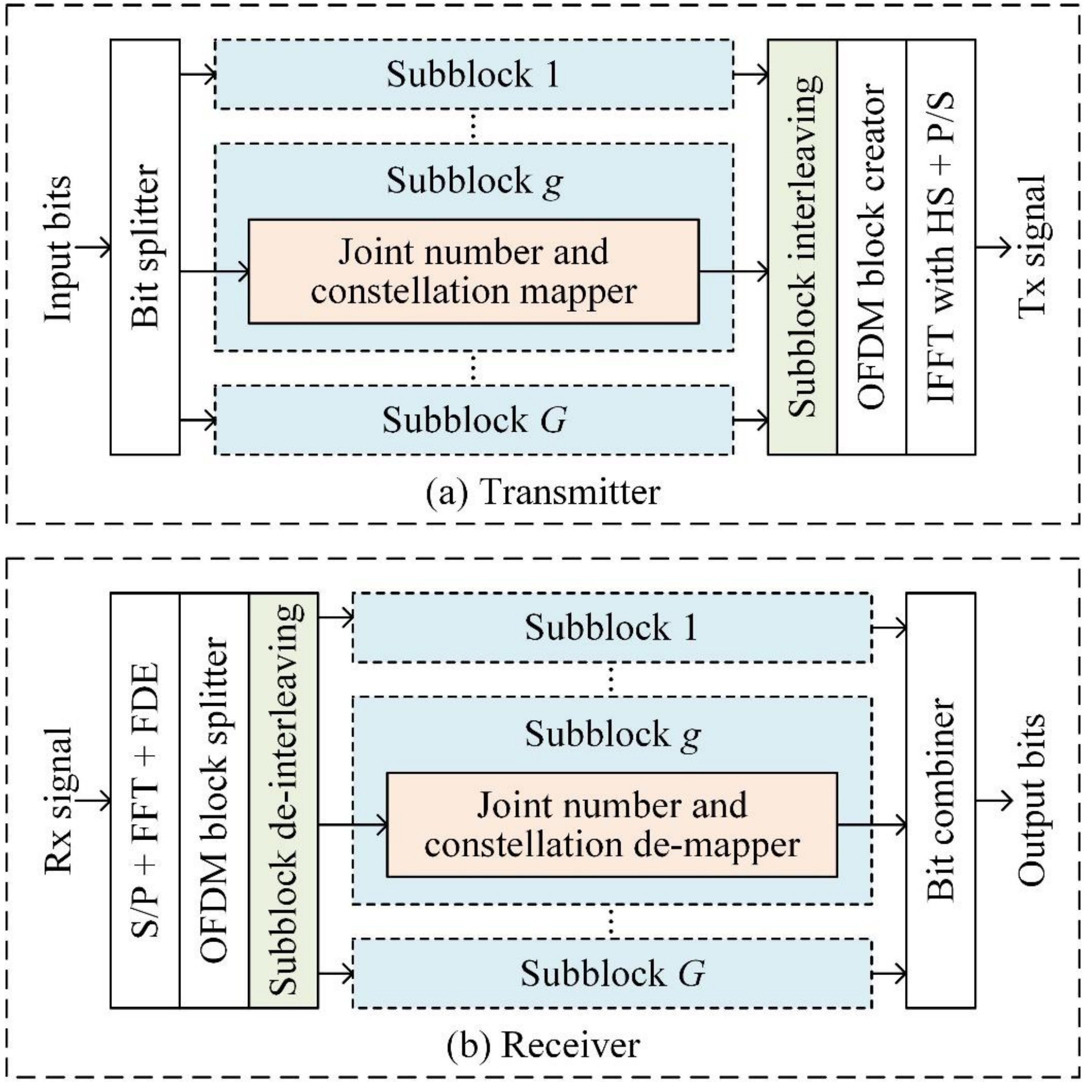
- Motivation: fully utilize the bandwidth of bandlimited low-pass U-LiFi systems

- Our approach

1. OFDM with subcarrier number modulation (OFDM-SNM)
2. Low-pass-aware subcarrier selection
3. Subblock interleaving (OFDM-ISNM)

SNM with *N*=4 and *k*∈{0,1,2}, *M*=4

Information bits	Subblocks	Number of activated subcarriers
[0 0 0 0]	[0,0,0,0]	0
[0 0 0 1]	$[S_1,0,0,0]$	1
…	…	…
[0 1 0 0]	$[S_4,0,0,0]$	1
[0 1 0 1]	$[S_1,S_1,0,0]$	2
[0 1 1 0]	$[S_1,S_2,0,0]$	2
…	…	…
[1 1 1 0]	$[S_3,S_2,0,0]$	2
[1 1 1 1]	$[S_3,S_3,0,0]$	2



Bandlimited U-LiFi systems: how much BW we can use?

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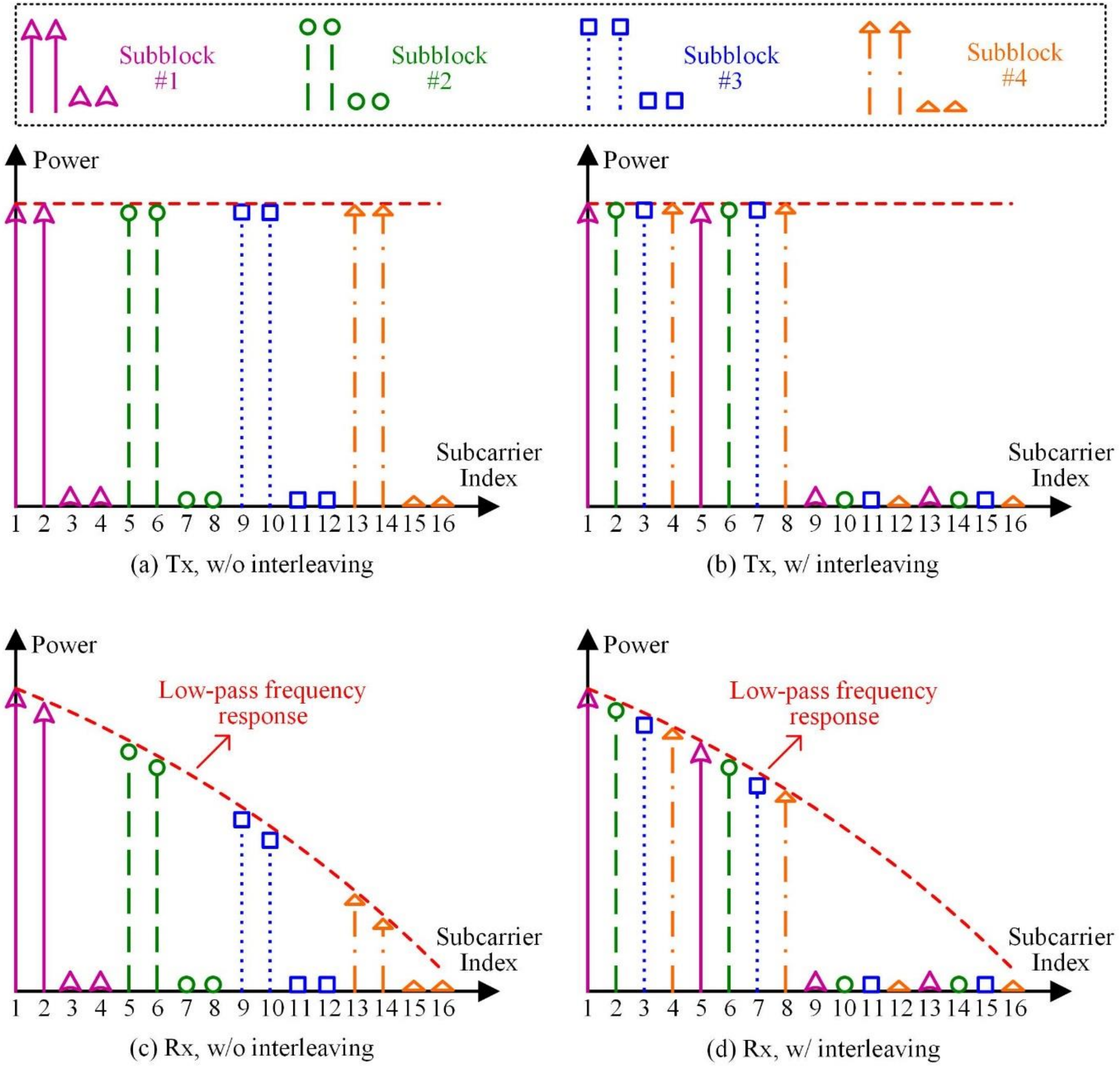
SNM with N=4 and k=2

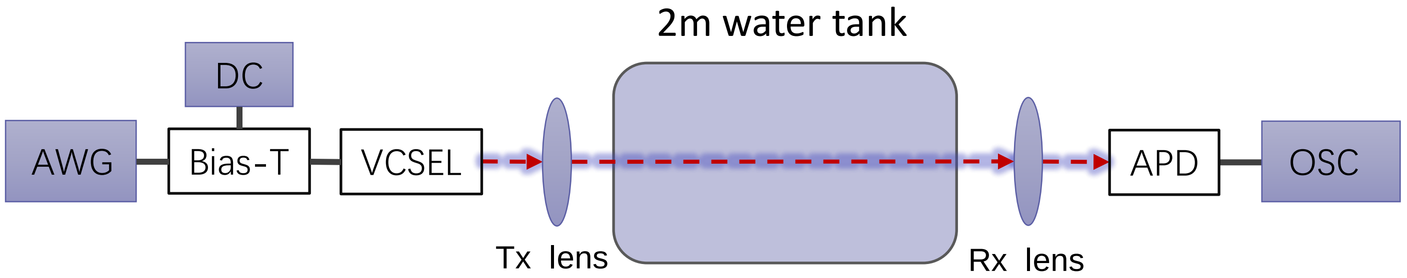


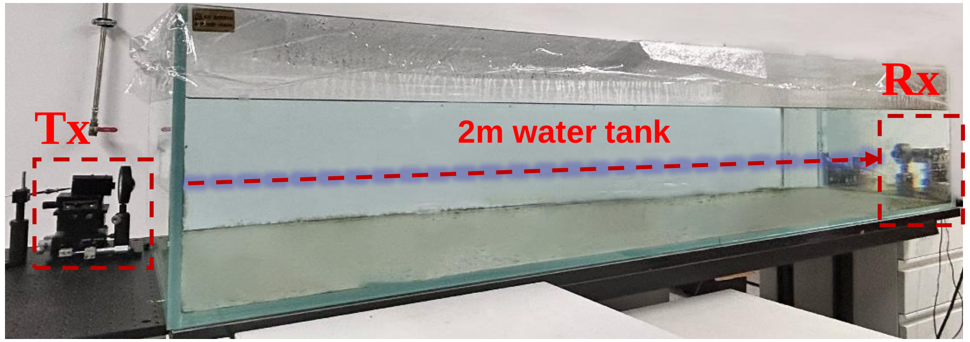
① **Subblock interleaving can efficiently address the low-pass effect**

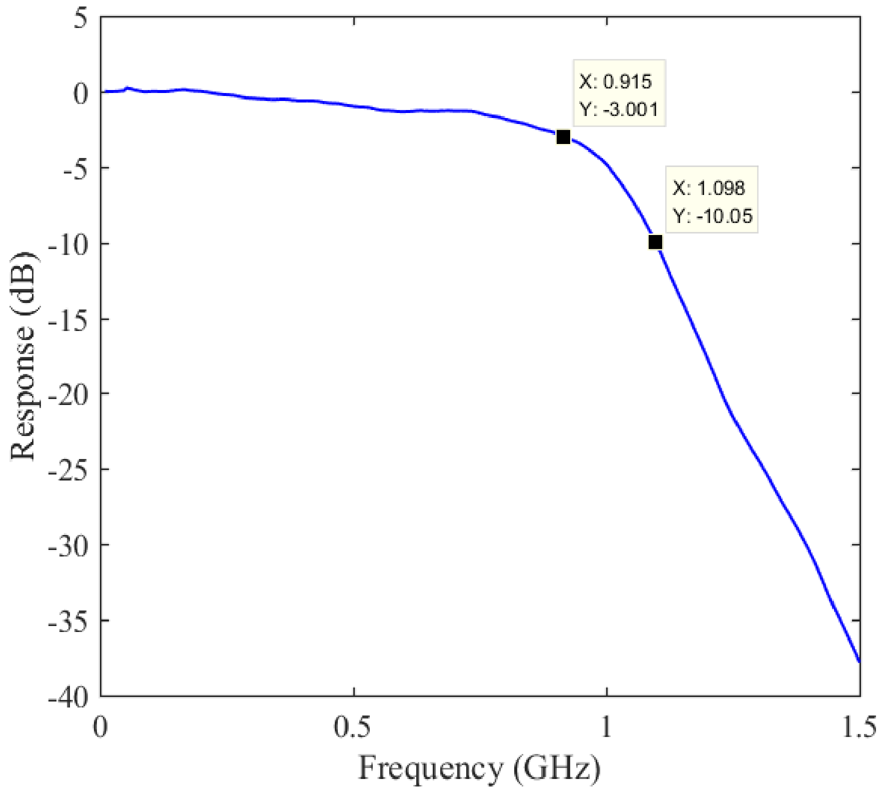
② **ISNM with N=4 and $k \in \{0,1,2\}$ can double the usable BW**

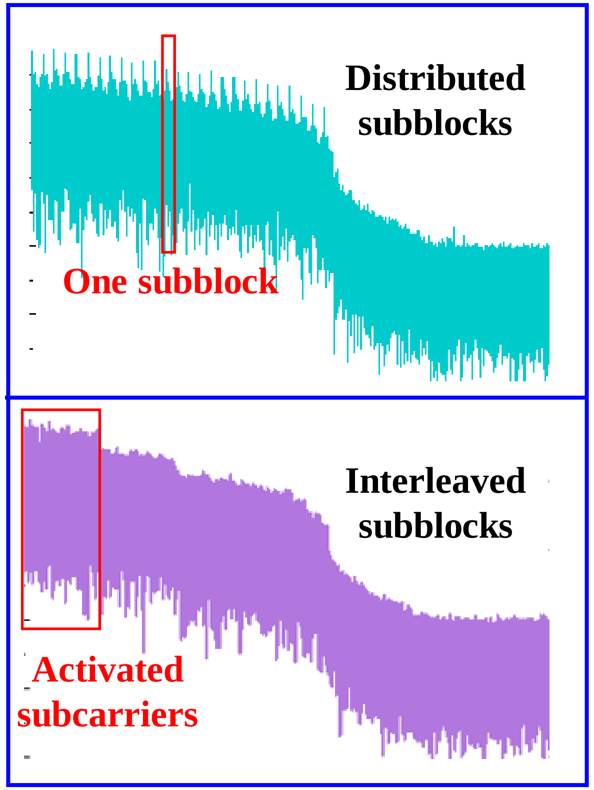
Bandlimited U-LiFi systems: how much BW we can use?

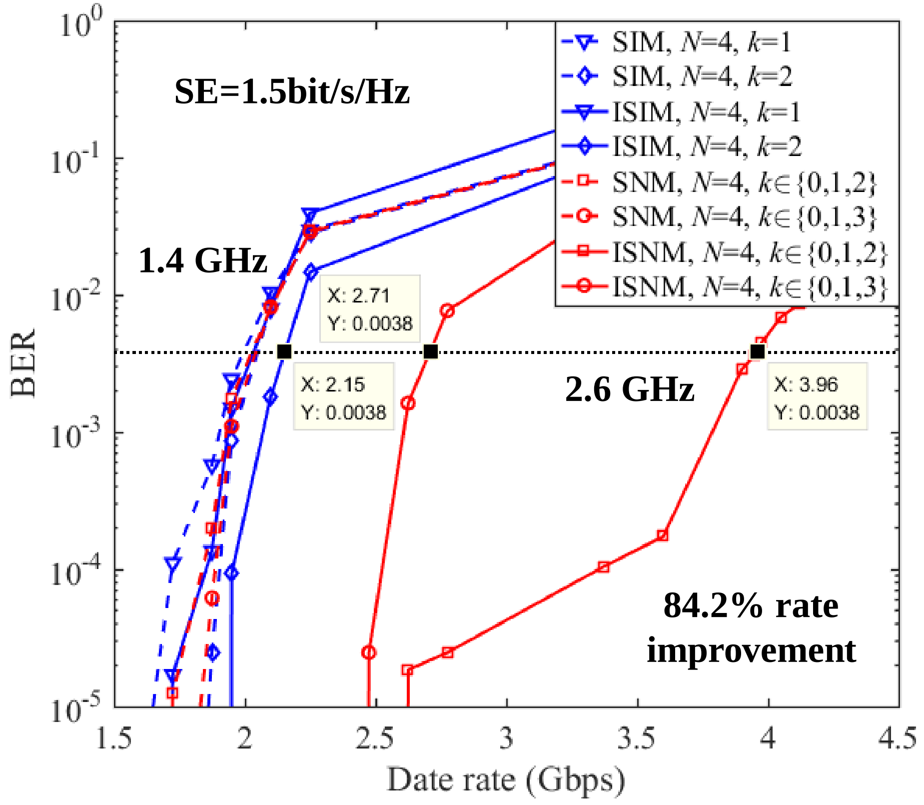
- Point-to-point U-LiFi experiments





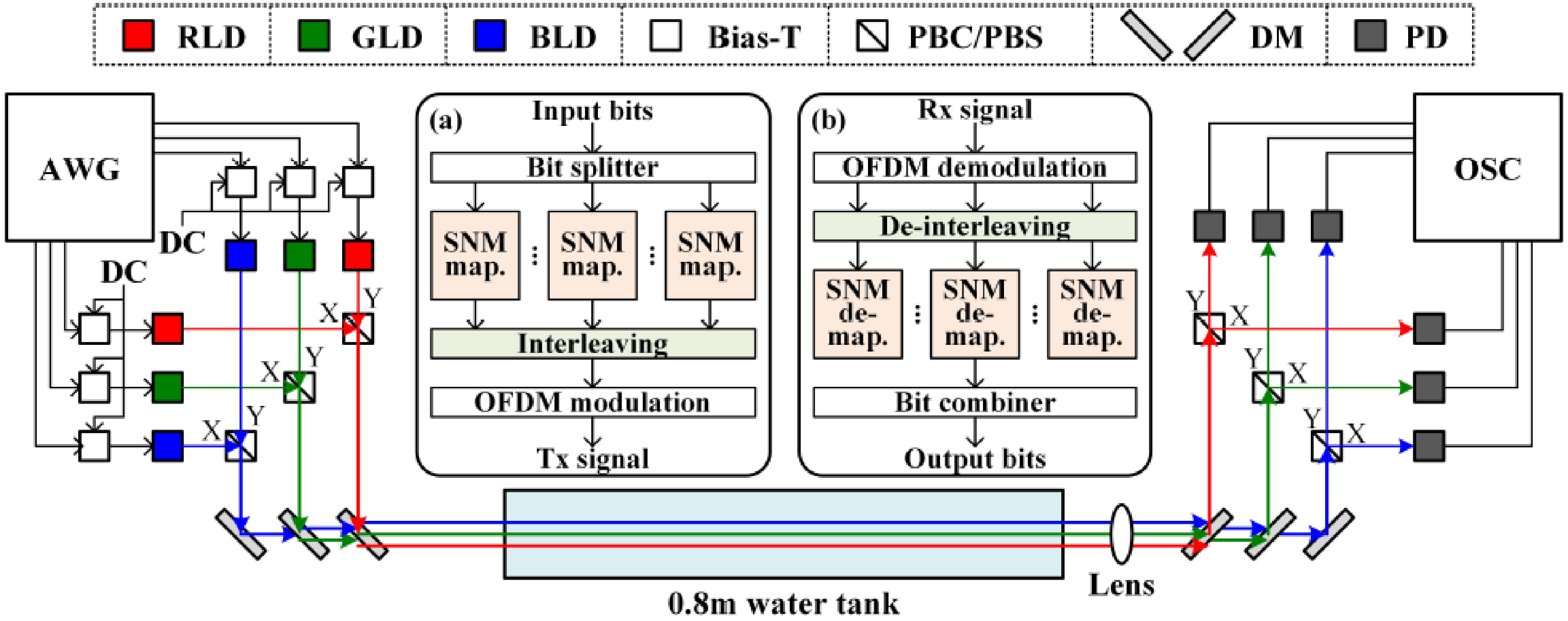


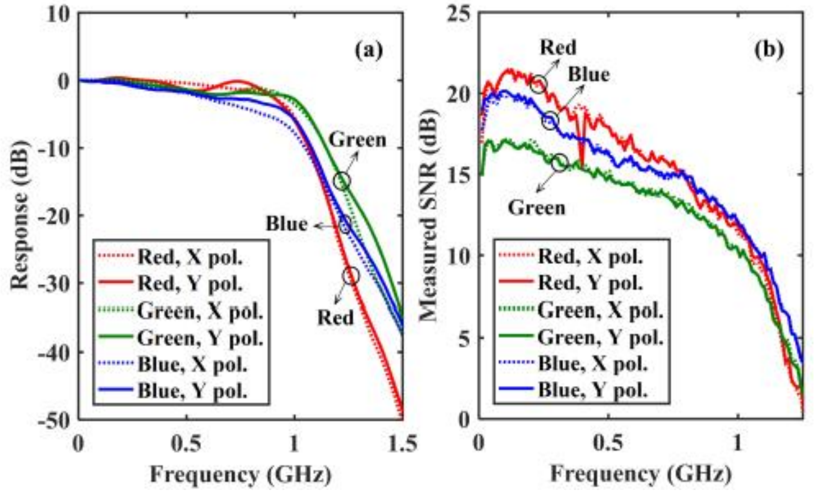


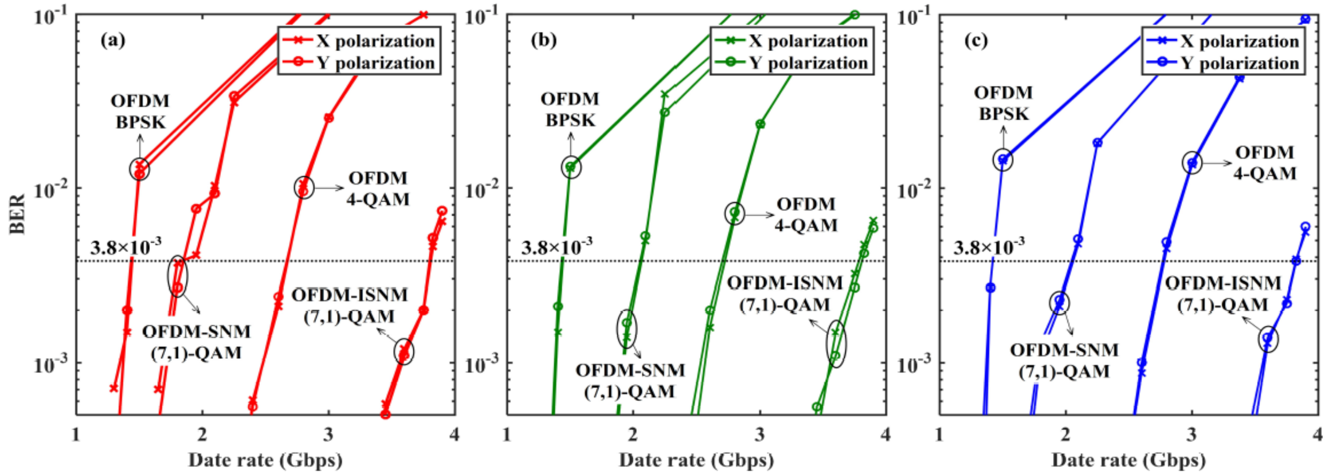


Bandlimited U-LiFi systems: how much BW we can use?

- Hybrid WDM/PolM U-LiFi experiments







Tab. 2: Comparison of different modulation schemes

Modulation scheme	Usable bandwidth	Achievable data rate
OFDM BPSK	1.4 GHz	8.4 Gbps
OFDM 4-QAM	1.4 GHz	16.8 Gbps
OFDM-SNM (7,1)-QAM	1.3 GHz	11.7 Gbps
OFDM-ISNM (7,1)-QAM	2.5 GHz	22.5 Gbps

78.6% BW extension

33.9% rate improvement

Thanks!