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ONIONCODE: Enabling Multi-priority Coding in LED-based Optical Camera Communications

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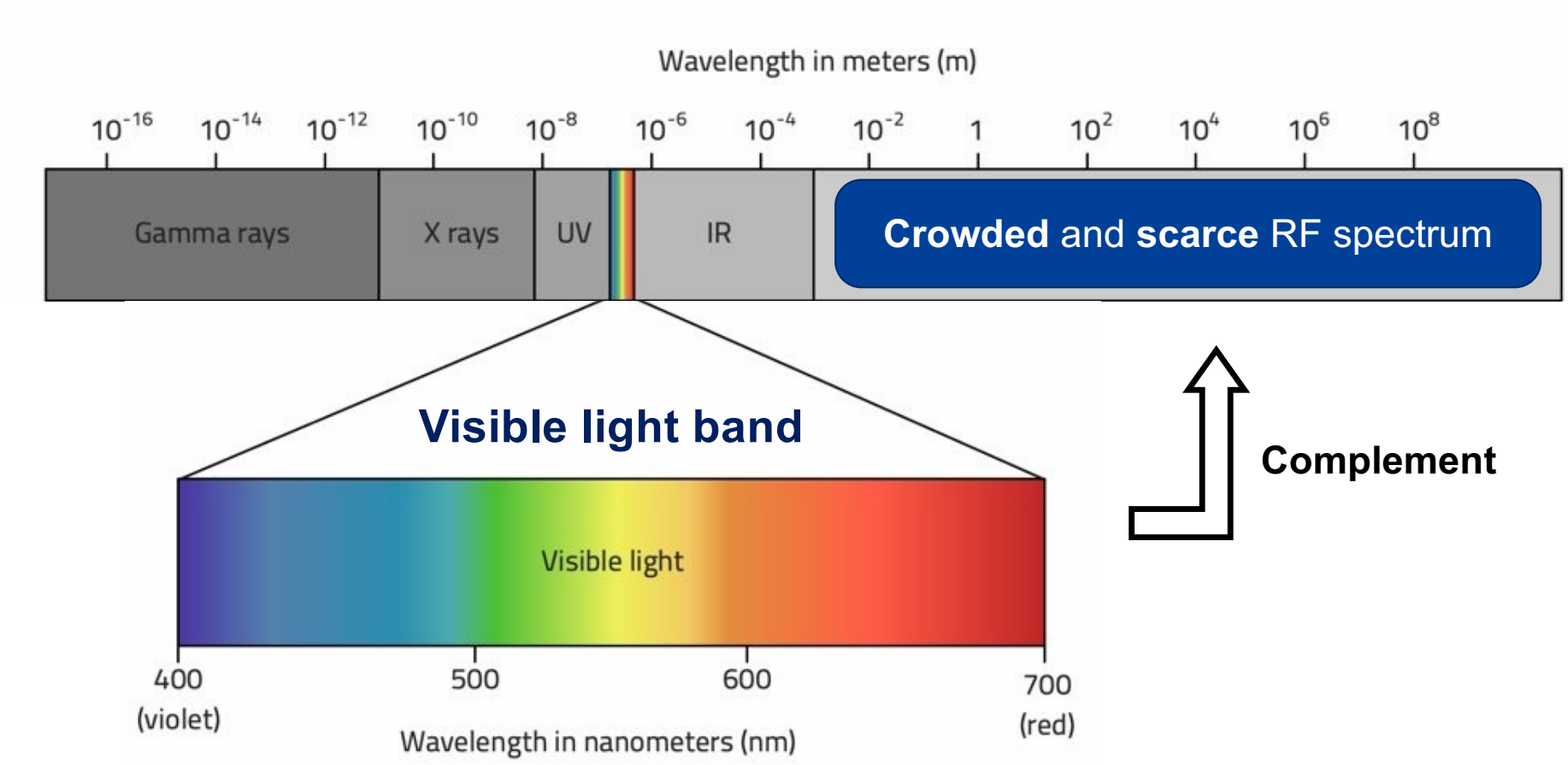
Outline

- **Background and Motivation**
- Design of OnionCode
- Coding Table Derivation
- OCC Prototype enhanced by OnionCode
- Evaluation
- Conclusion

From Radio Frequency (RF) to Visible Light

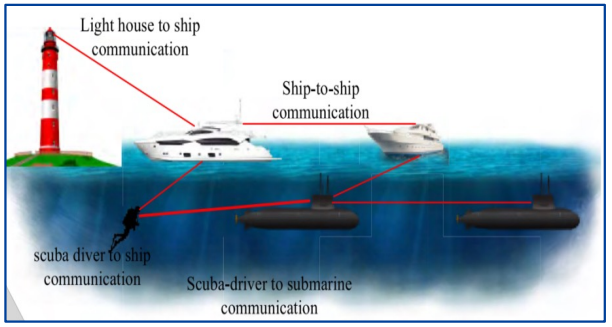


From Radio Frequency (RF) to Visible Light

Data sharing

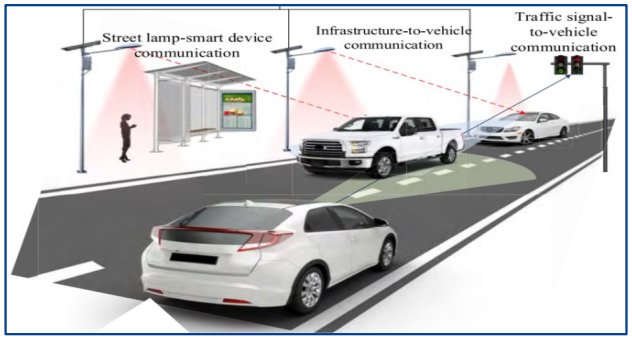
VLC v.s RF

- Not regulated and license-free
- Extremely rich spectrum
- Interference-free
- Widely-deployed infrastructure
- Energy efficient

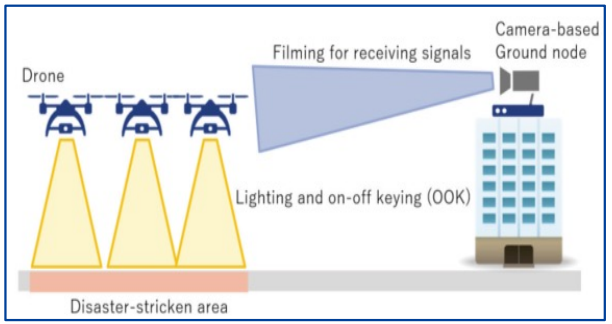


Underwater communication

Indoor positioning

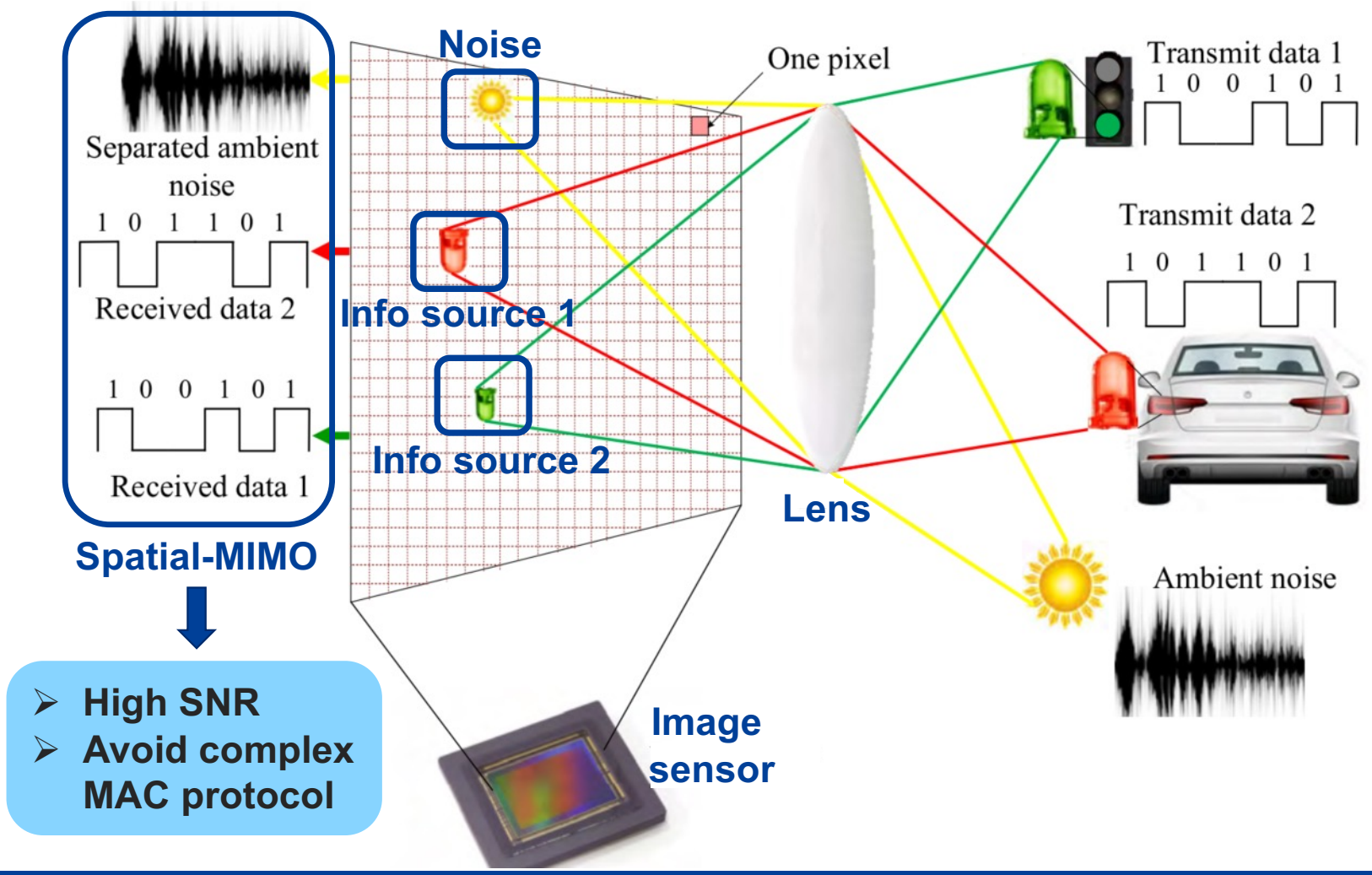


V2X communication



Drone communication

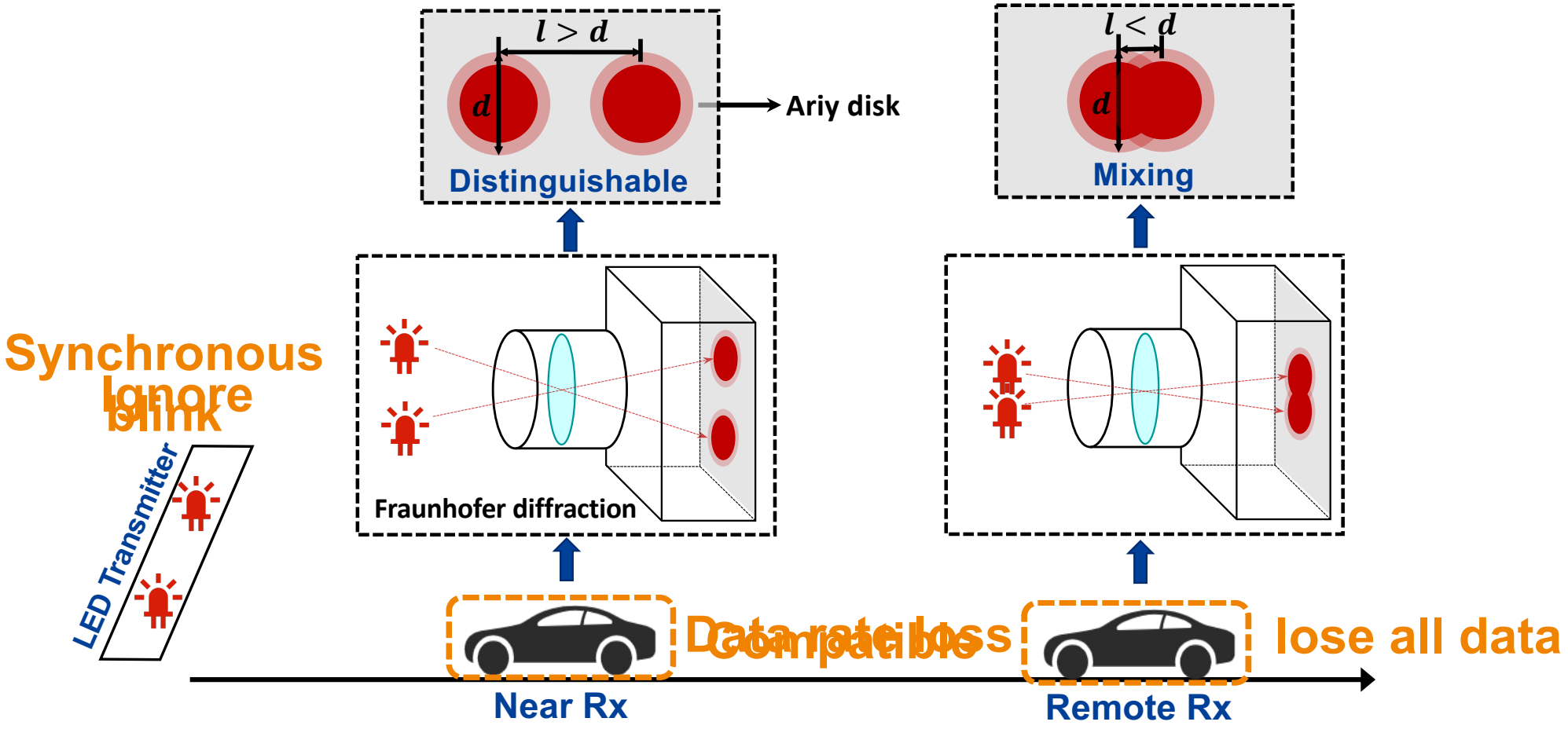
Optical Camera Communication (OCC)



- High SNR
- Avoid complex MAC protocol

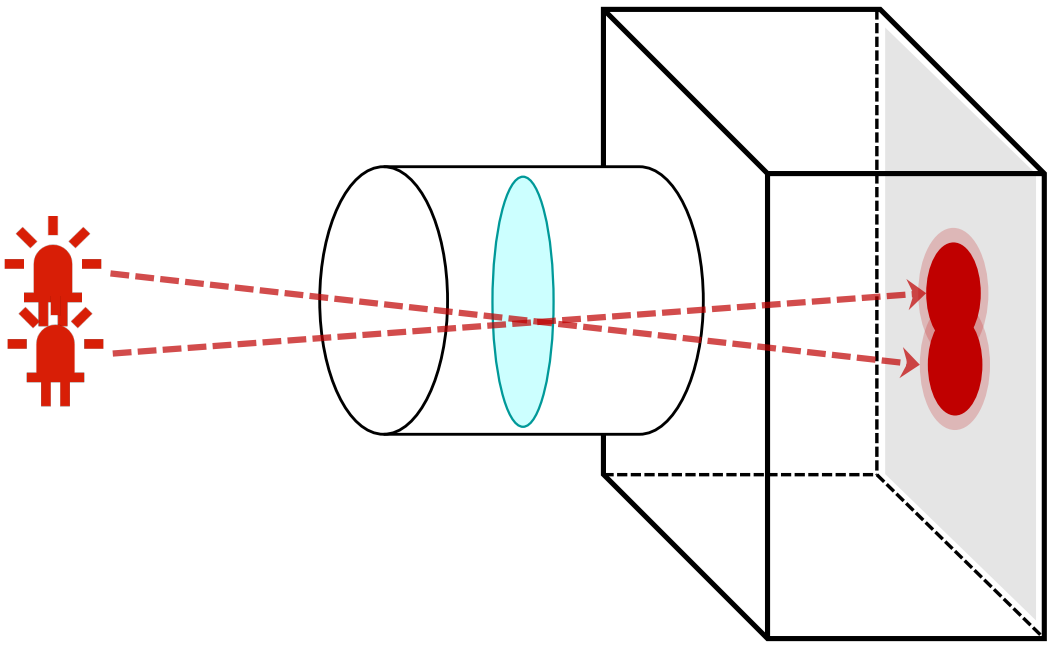
Limitation in one-to-many OCC communication

➢ **Distance** limits the performance in one-to-many OCC communcation.

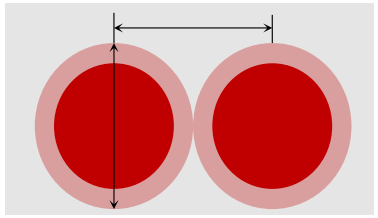


Rayleigh Criterion

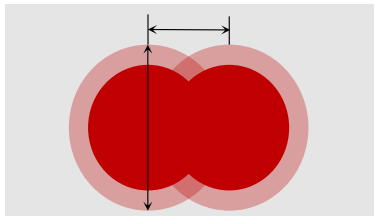
➢ **Limited angular resolution** of the optical imaging instruments



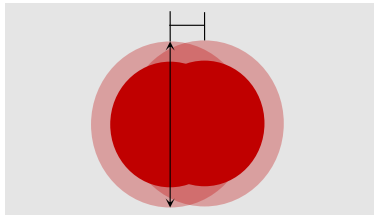
Fraunhofer diffraction & Airy disk



Disjoint



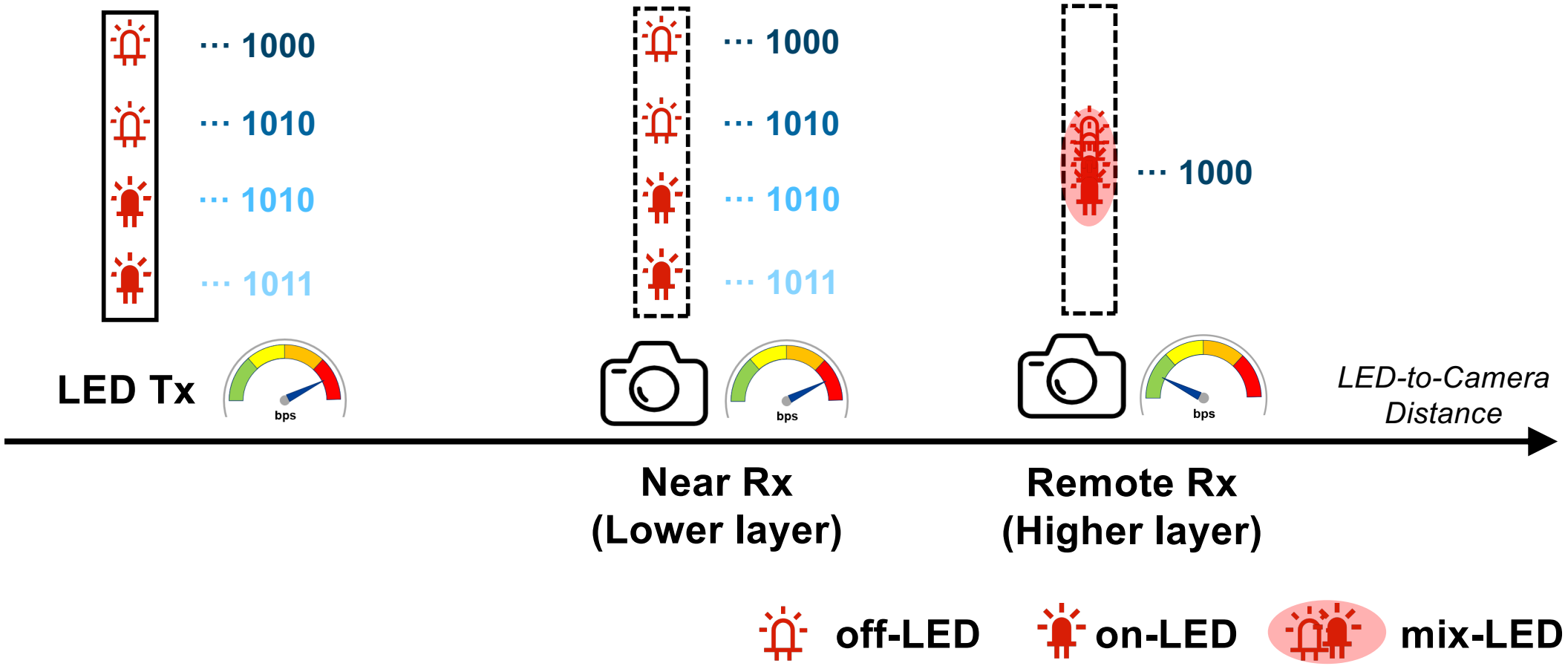
Critical
Rayleigh criterion



Mixing

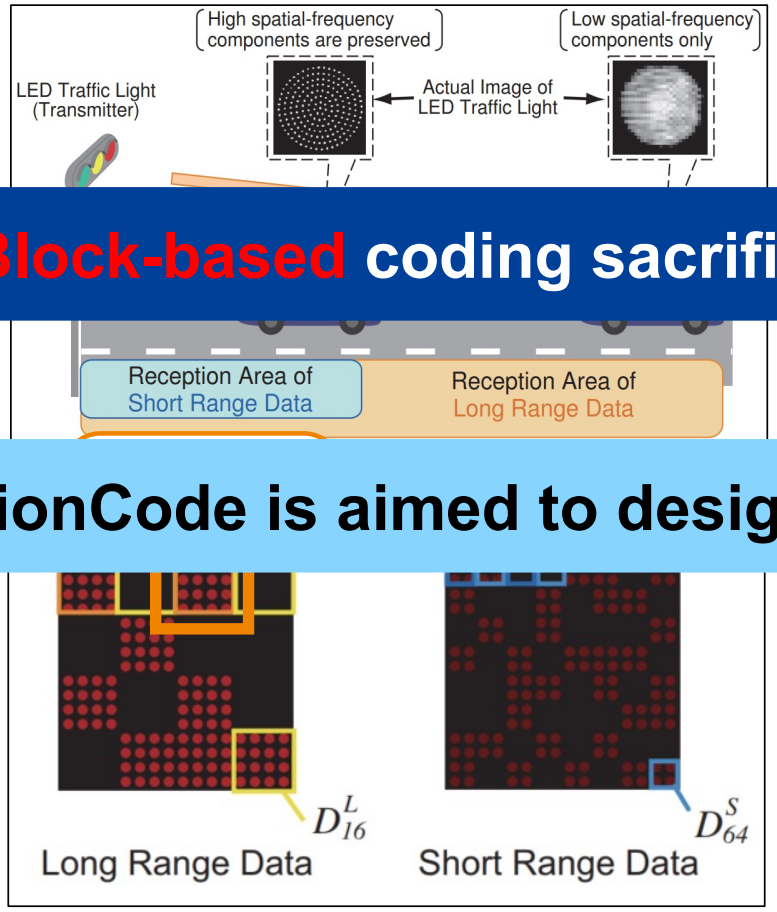
Hierarchical Coding in Physical Layer

- Dynamic range of channel capacity

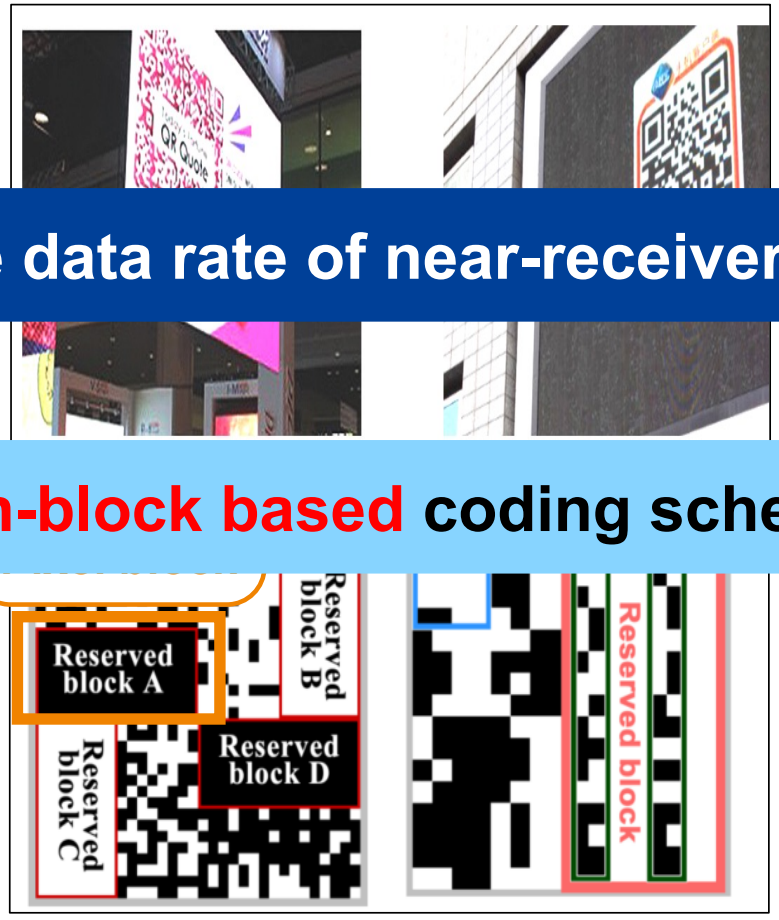


Motivation - Data rate sacrificing in existing works

➢ **Overlay Coding** [IEEE ITSC, 2011]



➢ **Strata** [ACM MobiCom, 2014]



Block-based coding sacrifices the data rate of near-receivers !

OnionCode is aimed to design a non-block based coding scheme.

Outline

- Background and Motivation
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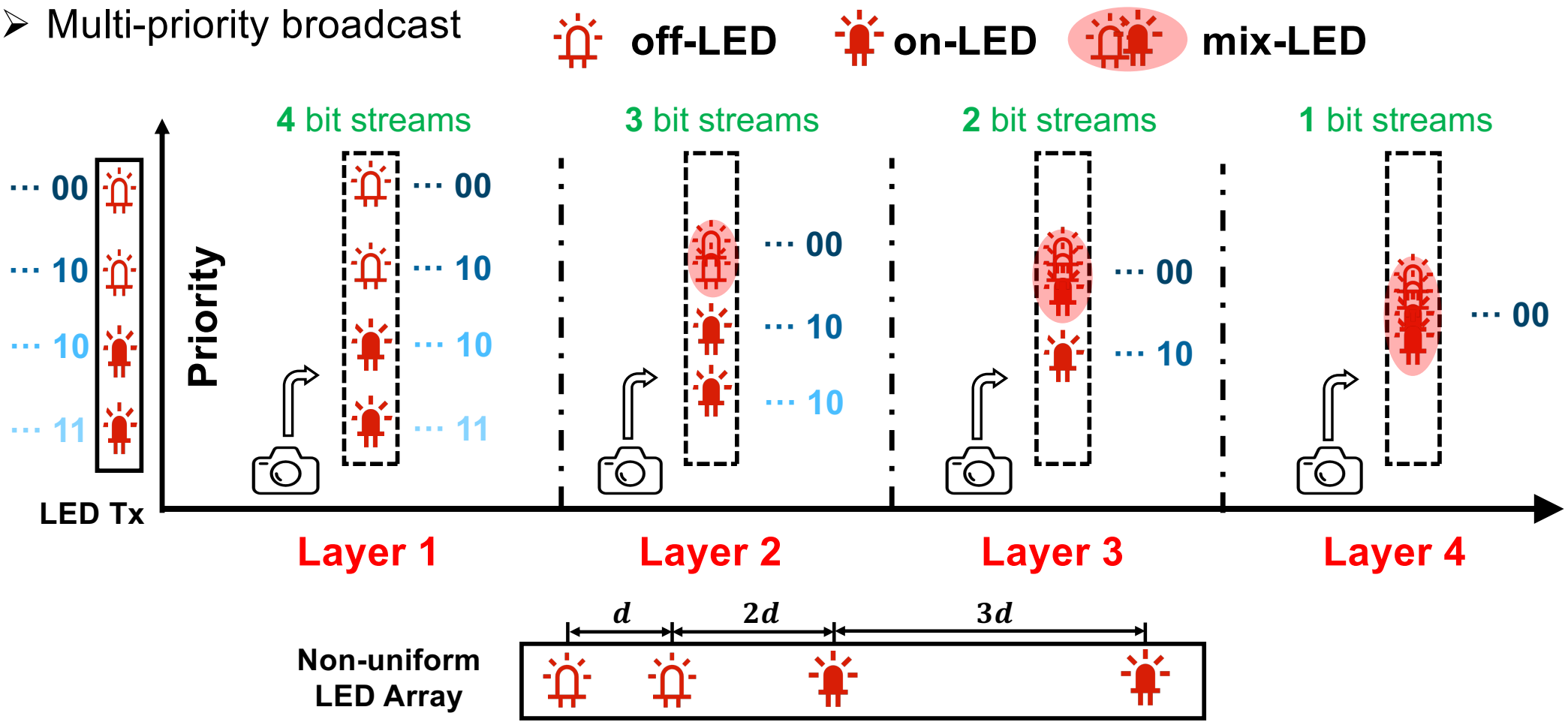
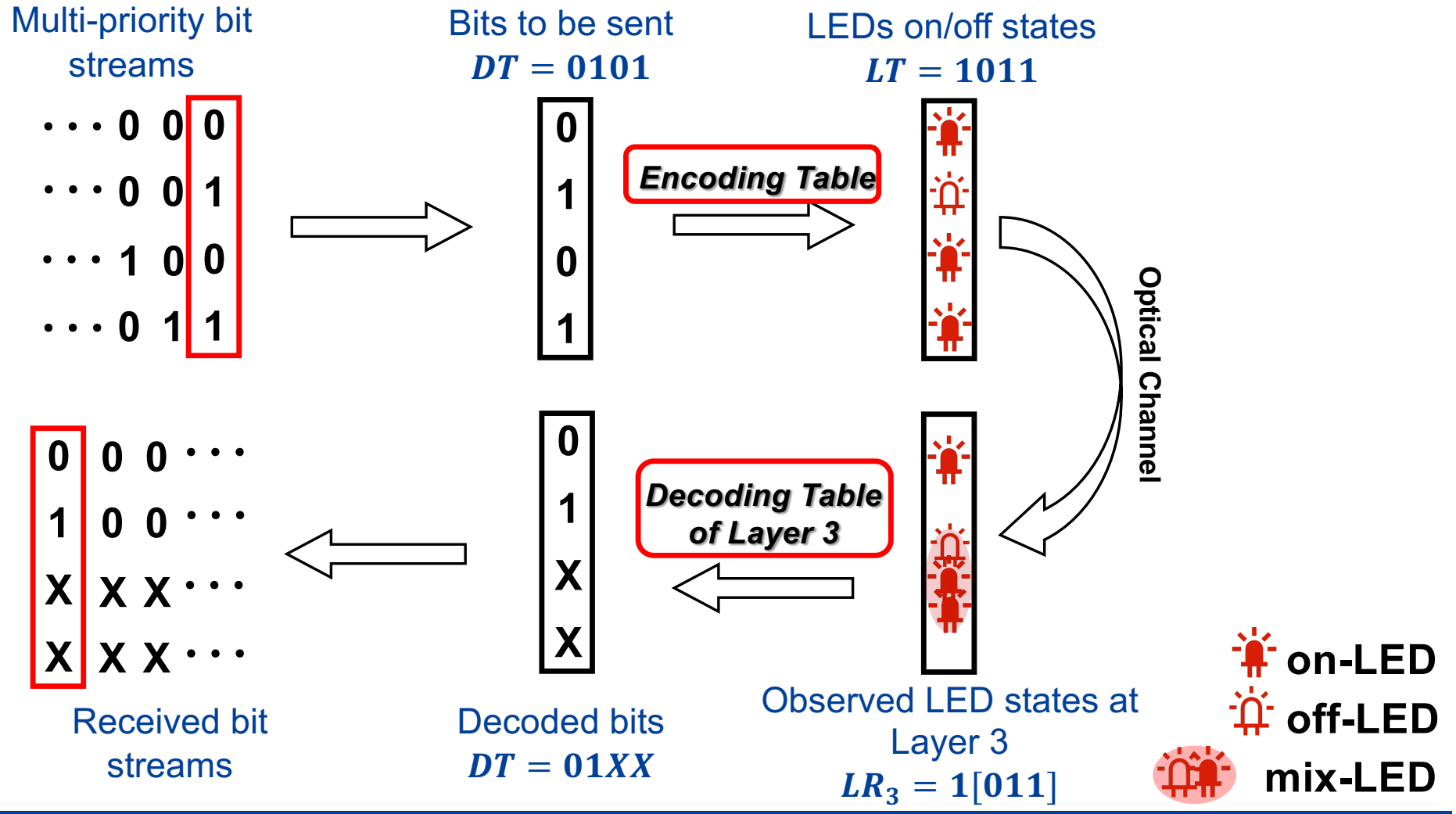
Hierarchical Coding in Physical Layer

➢ Multi-priority broadcast



Transmission Model of OnionCode



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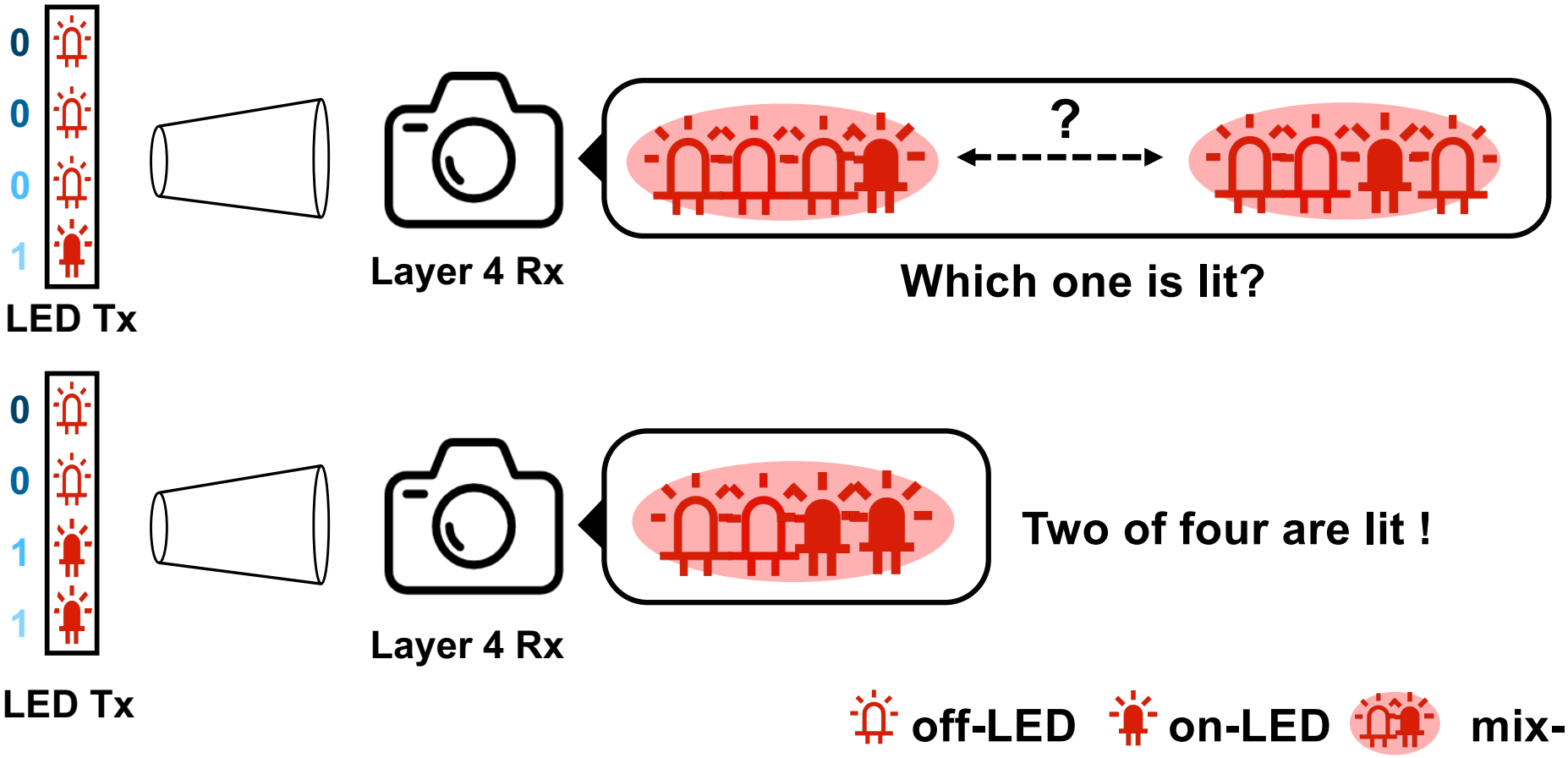
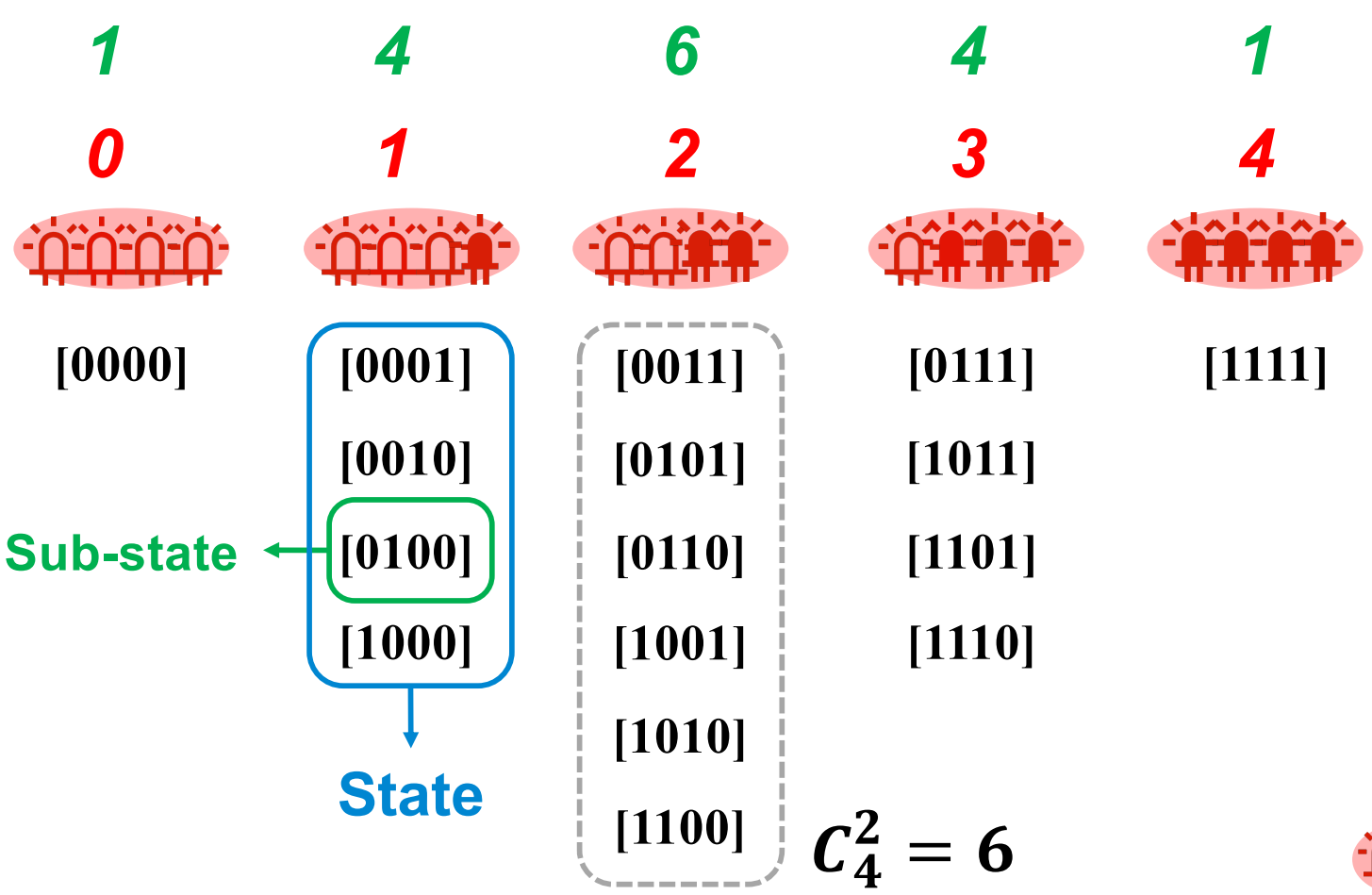
Key insight of OnionCode

- Which one is lit? But two of four are lit!



LED State Space

- LED state space of a layer 4 receiver



En / Decoding Table of OnionCode

L1

0000	0001	0010	0011	0100	0101	0110	0111
1000	1001	1010	1011	1100	1101	1110	1111

L2

000X		001X		001X					
00[00]	00[01]	00[11]	01[00]	01[01]	01[11]	10[00]	10[01]	10[11]	11[00]	11[01]	11[11]
	00[10]			01[10]			10[10]			11[10]	

L3

	00XX		00XX	01XX		01XX	
0[000]	0[001]	0[011]	0[111]	1[000]	1[001]	1[011]	1[111]
	0[010]	0[101]			1[010]	1[101]	
	0[100]	0[110]			1[100]	1[110]	

L4

1XXX	0XXX	1XXX	0XXX	1XXX
[0000]	[0001]	[0011]	[0111]	[1111]
	[0010]	[0101]	[1011]	
	[0100]	[0110]	[1101]	
	[1000]	[1001]	[1110]	
		[1010]		
		[1100]		

$2^2 = 4$

0 0 X X

0 1 X X

$2^3 = 8$

0 X X X

1 X X X

Bits to be decoded

En / Decoding Table of OnionCode

L1

1000	0000	0001	1001	0010	1010	1011	0011
0000	0001	0010	0011	0100	0101	0110	0111
0100	1100	1101	0101	1110	0110	0111	1111
1000	1001	1010	1011	1100	1101	1110	1111

Decoding Table of Layer 1

Encoding Table

L2

100X	000X	100X	001X	101X	001X	010X	110X	010X	111X	011X	111X
00[00]	00[01]	00[11]	01[00]	01[01]	01[11]	10[00]	10[01]	10[11]	11[00]	11[01]	11[11]
	00[10]			01[10]			10[10]			11[10]	

Decoding Table of Layer 2

L3

10XX	00XX	10XX	00XX	01XX	11XX	01XX	11XX
0[000]	0[001]	0[011]	0[111]	1[000]	1[001]	1[011]	1[111]
	0[010]	0[101]			1[010]	1[101]	
	0[100]	0[110]			1[100]	1[110]	

Decoding Table of Layer 3

L4

1XXX	0XXX	1XXX	0XXX	1XXX
[0000]	[0001]	[0011]	[0111]	[1111]
	[0010]	[0101]	[1011]	
	[0100]	[0110]	[1101]	
	[1000]	[1001]	[1110]	
		[1010]		
		[1100]		

Decoded bits

⇧

LED state

Decoding Table of Layer 4

En / Decoding Table of OnionCode

L1	1000 0000	0000 0001	0001 0010	1001 0011	0010 0100	1010 0101	1011 0110	0011 0111
	0100 1000	1100 1001	1101 1010	0101 1011	1110 1100	0110 1101	0111 1110	1111 1111
L2	100X 00[00]	000X 00[01] 00[10]	100X 00[11]	001X 01[00]	101X 01[01] 01[10]	001X 01[11]	010X 10[00]	110X 10[01] 10[10]	010X 10[11]	111X 11[00]	011X 11[01] 11[10]	111X 11[11]
L3	10XX 0[000]	00XX 0[001] 0[010] 0[100]	10XX 0[011] 0[101] 0[110]	00XX 0[111]	01XX 1[000]	11XX 1[001] 1[010] 1[100]	01XX 1[011] 1[101] 1[110]	11XX 1[111]
L4	1XXX [0000]	0XXX [0001] [0010] [0100] [1000]	1XXX [0011] [0101] [0110] [1001] [1010] [1100]	0XXX [0111] [1011] [1101] [1110]	1XXX [1111]			

Sending bits

1100

⇩

1001 ⇨

LED states

110X Rx bits

⇧

10[01] ⇦

Rx states

11XX Rx bits

⇧

1[001] ⇦

Rx states

1XXX Rx bits

⇧

[1001] ⇦

Rx states

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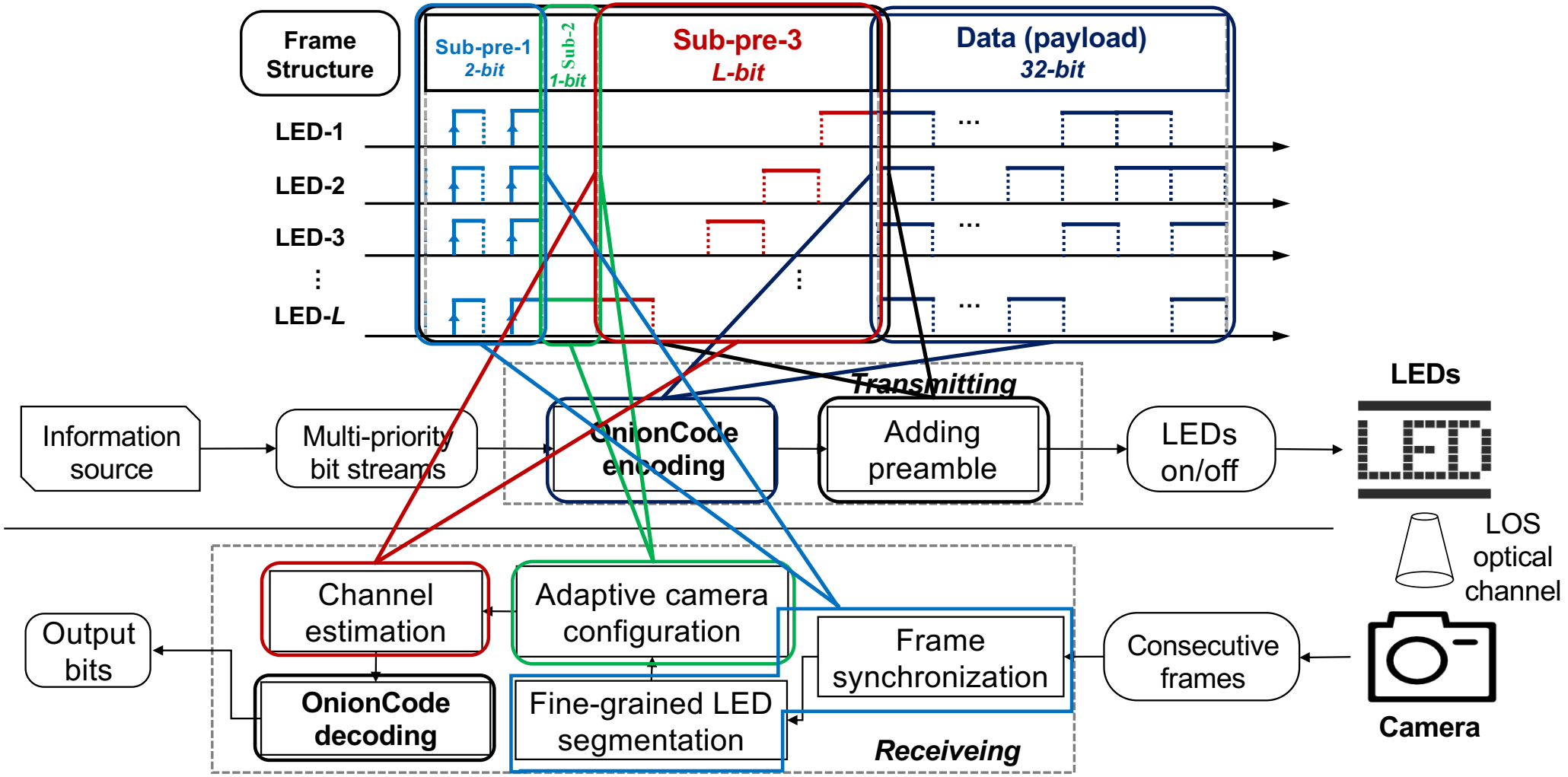
OCC Prototype enhanced by OnionCode



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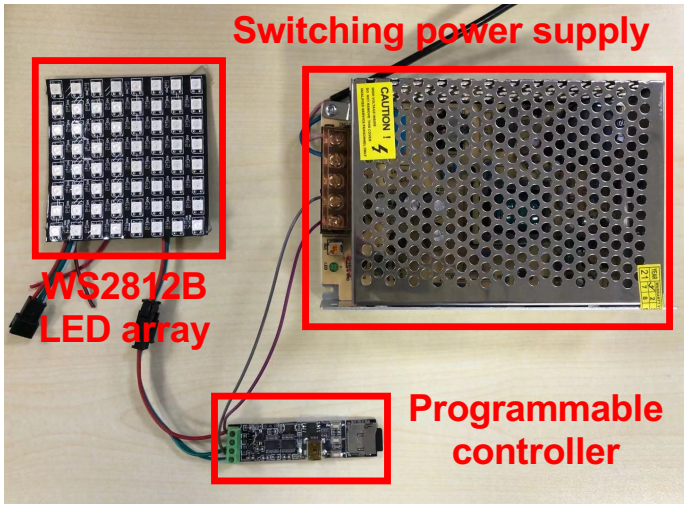
Experiments

- Sender hardware



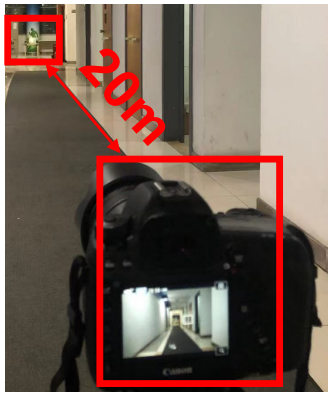
- Receiver hardware

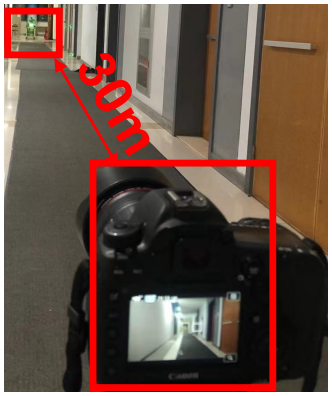
Cannon EOS 5D Mark IV (1080p, 50Hz)

DJI Zenmuse H20 (1080p, 50Hz)

iPhone X (1080p, 50Hz)

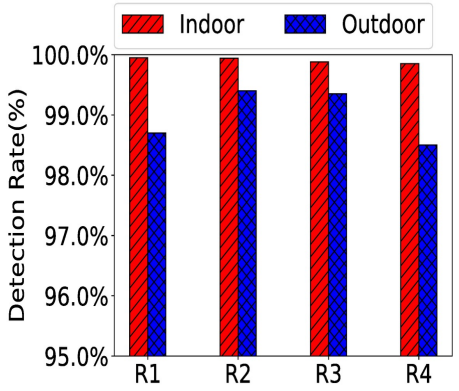
- Experiment setup
  (4 layer receivers at 10 ~ 40m from sender)

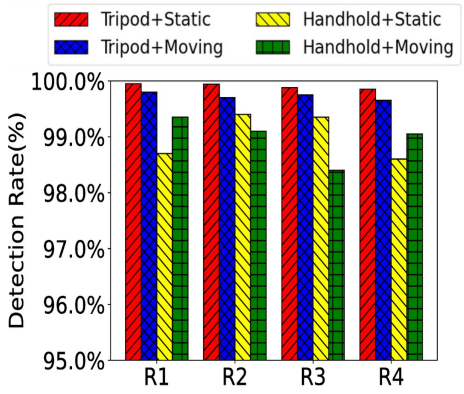




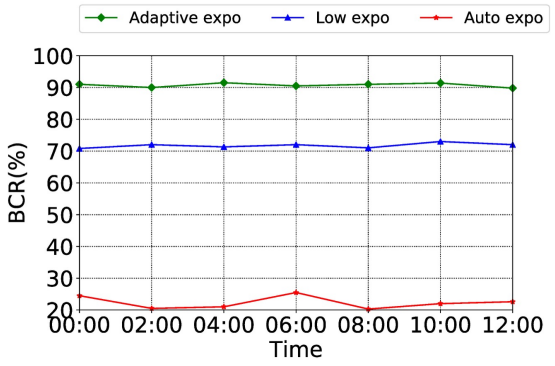
Experiments

➢ Preamble detection rate under various environment factors

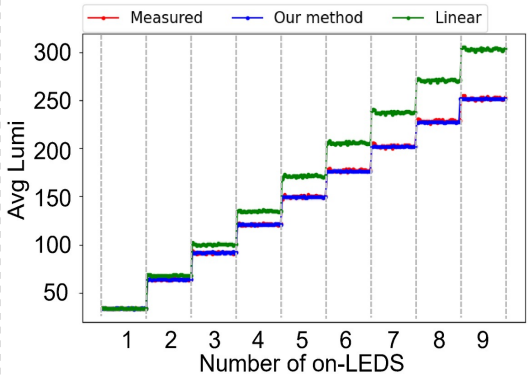




➢ Adaptive camera configuration

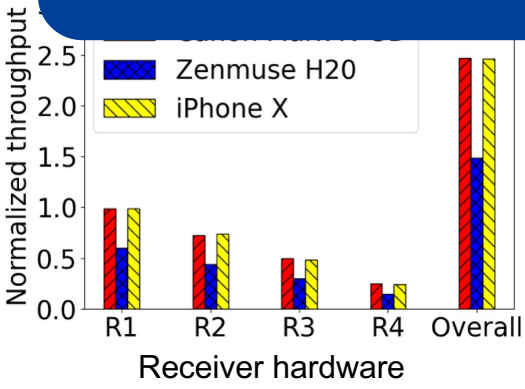


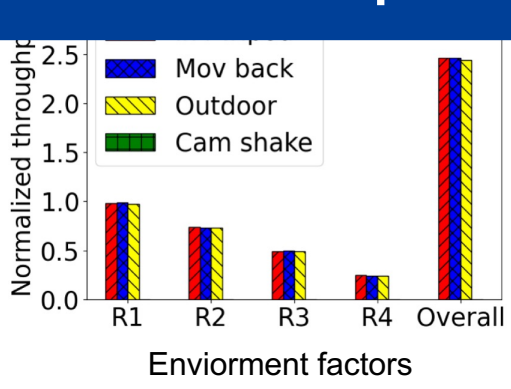
➢ Channel estimation

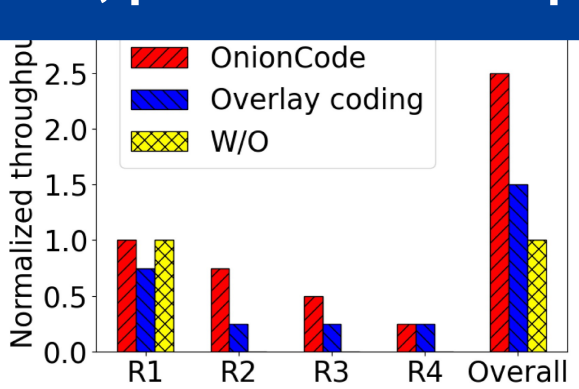


➢

For more detailed information experiment results, please read our paper ☺







67% ↑

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Conclusion

OnionCode enables multi-priority hierarchical transmission in OCC:

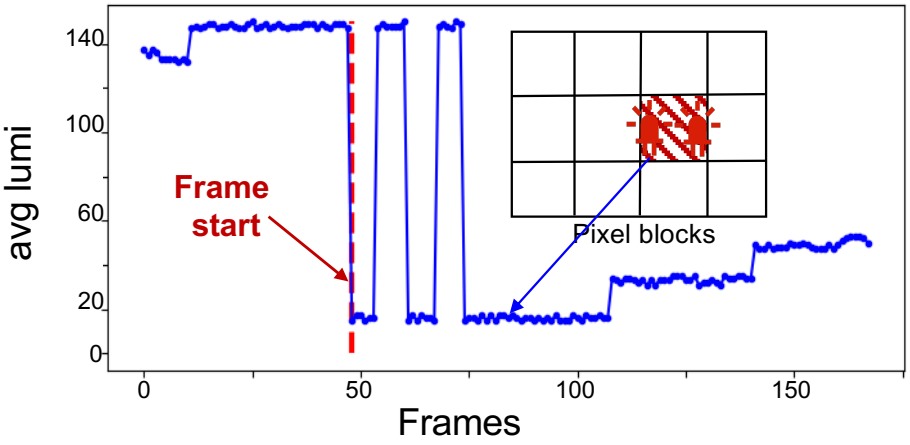
- ✓ Propose a novel hierarchical coding scheme
  - ➢ Non-block-based
  - ➢ Dynamic adjustment of data rate
  - ➢ 67% increase in overall throughput
- ✓ Implenment an OCC prototype enhanced by OnionCode
  - ➢ Commercial off-the-shelf hardware
  - ➢ A series of communication mechanism

Thanks!

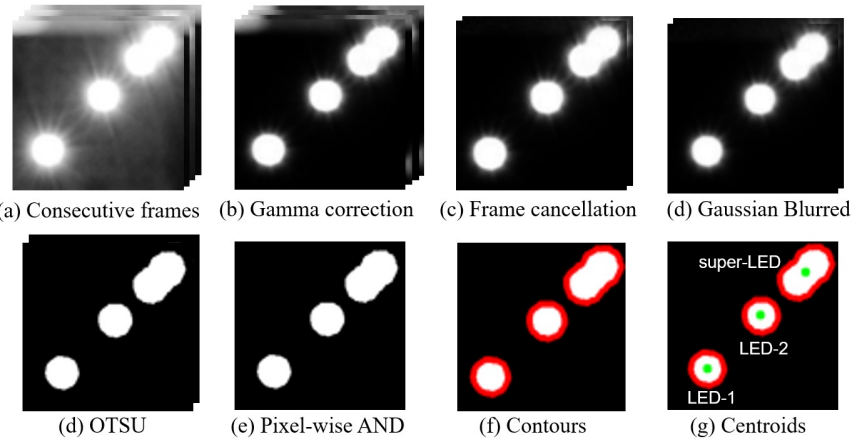
Q & A

Communication mechanisms in OnionCode prototype

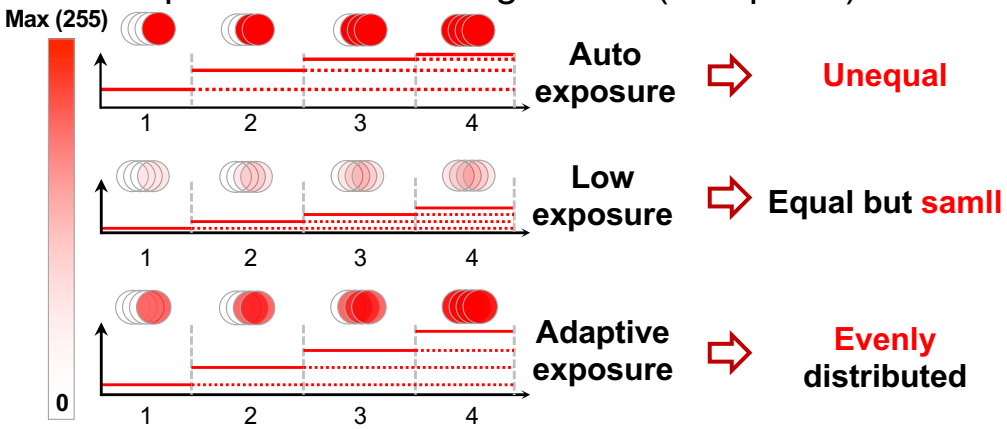
➢ Frame synchronization (sub-pre-1)



➢ Fine-grained LED segmentation (sub-pre-2)



➢ Adaptive camera configuration (sub-pre-2)



➢ LED channel estimation (sub-pre-3)