Efficient flicker-free FEC codes using Knuth's balancing algorithm for VLC

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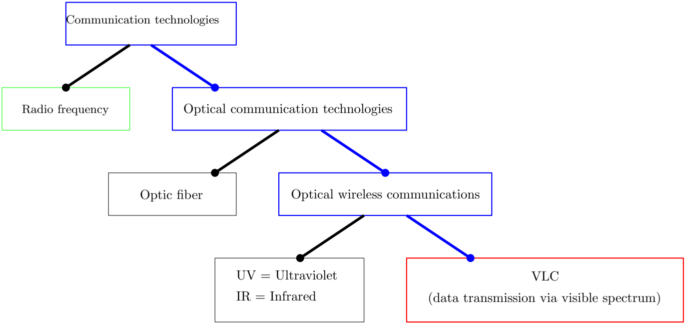
VLC (Visible light communication)

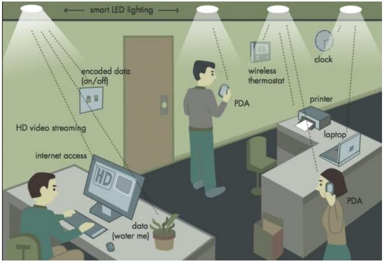
- VLC is a short range optical wireless communication technology which uses modulated light beam



- Why do we use VLC?

VLC applications [1]

- Indoor/outdoor optical wireless communication (OWC)
- Robotics
- Li-Fi network



[1]. A. R. Ndjiongue, “Visible light communications (VLC) technology”, *Wiley*, 2015.

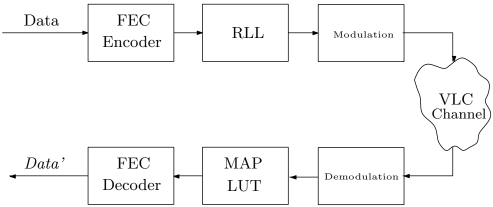
Challenges in VLC

- How to perform efficient dimming while avoiding flickering in the channel?
  - Avoiding flickering: limit run-lengths of 1's or 0's.
  - Efficient dimming: varying the weight (amount of 1) of the transmitted codeword.

Contribution

- Proposed to use Knuth's balancing algorithm (KA) to incur 50% dimming in VLC.
  - Less redundancy compared to RLL codes based approaches.
  - Flexible transmission rates.

Classical VLC channel



IEEE standard for local and metropolitan area networks part 15.7: Short-range wireless optical communication using visible light, IEEE Std 802.15.7-2011, pp. 1–286, Sept 2011

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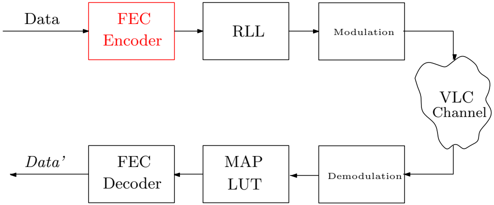

- Concatenated codes scheme: Reed Solomon (RS) codes are deployed as inner codes and convolutional codes (CC) as outer codes.

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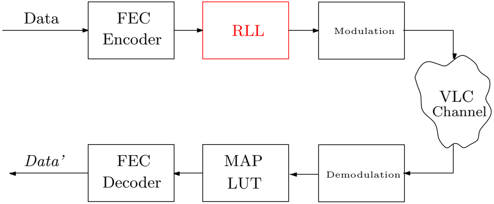

- Run length limited (RLL): 1B2B, 4B6B and 8B10B
  - 1B2B: 0 $\rightarrow$ 01 and 1 $\rightarrow$ 10
  - A $\alpha B \beta B$ RLL code maps all length α words to 2^{α} DC-free codewords of length β.
  - The lengthier the code, the higher the decoding complexity!

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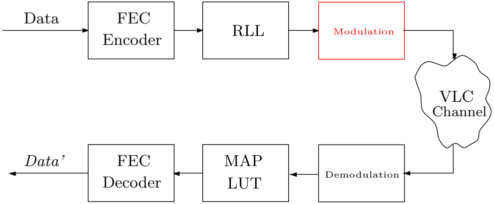
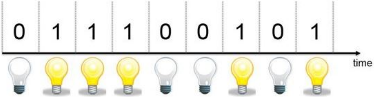


- On-off keying (OOK) / Variable pulse position modulation (VPPM) / Colour shift keying (CSK)
- OOK



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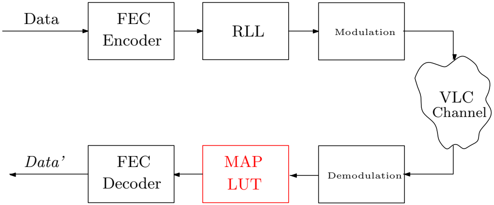

- Complex decoding (MAP) based on look-up tables
- Limited error correction capabilities!

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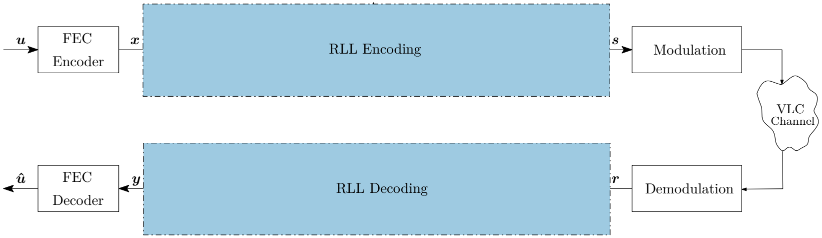
Proposed scheme



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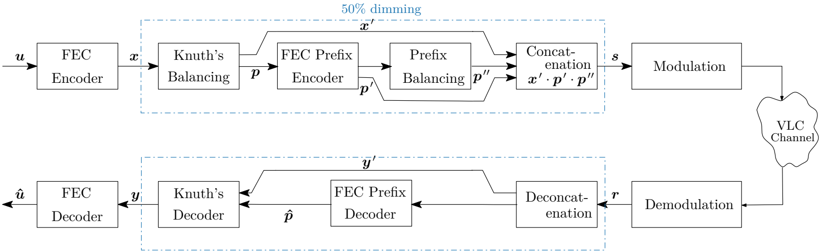

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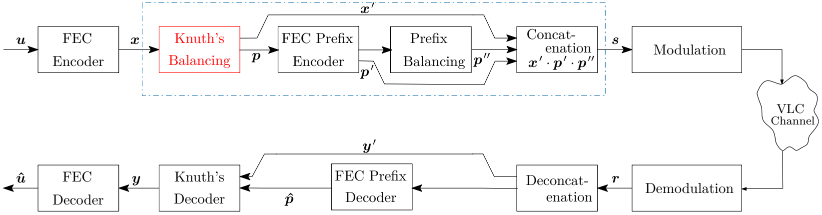
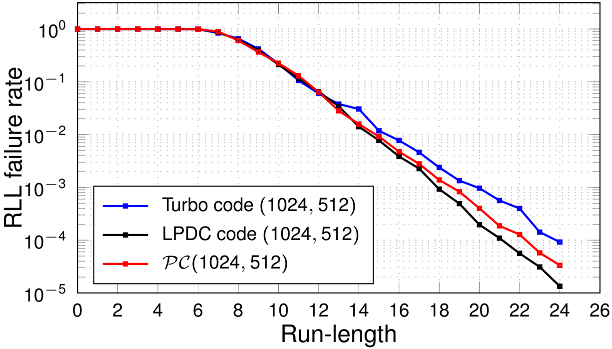


- 101111 → 001111|<u>001</u> → 011111|<u>010</u> → 010111|<u>011</u> → 010011|<u>100</u>

- Prefix length up to $\boldsymbol{p} = \log_2(\boldsymbol{x})$

D. E. Knuth, "Efficient balanced codes," IEEE Transactions on IT, vol 32, no. 1, pp. 51–53, 1986

Flickering mitigation for various FEC codes



- At 50% dimming; the number of frames is validated by 100 "frame errors" for each run-length.
- We chose polar codes!

Flickering mitigation threshold

- Using the lowest optical clock rate of 200 kHz;
- With the MFTP of 5 ms (= eye-safe frequency of 200 Hz);
- $L \times \frac{1}{200 \text{ kHz}} < \frac{1}{200 \text{ Hz}} \rightarrow L = 1000$;
- For a threshold of 20$\times$ less than L, $t = 1000/20 = 50$;

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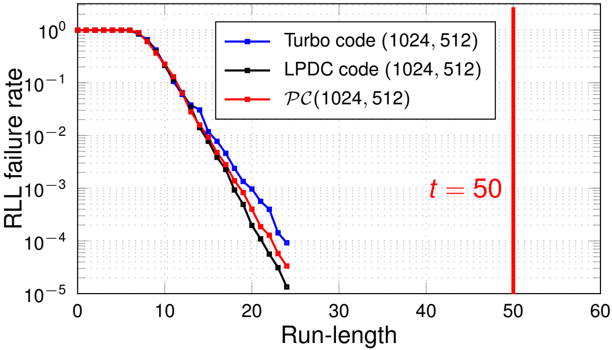

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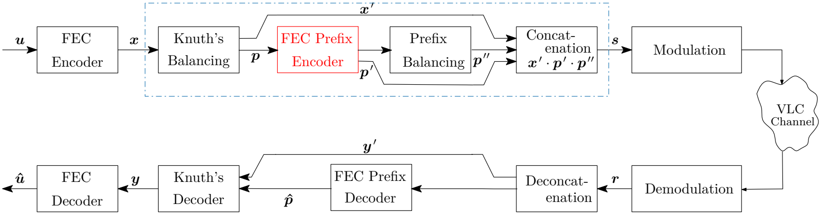
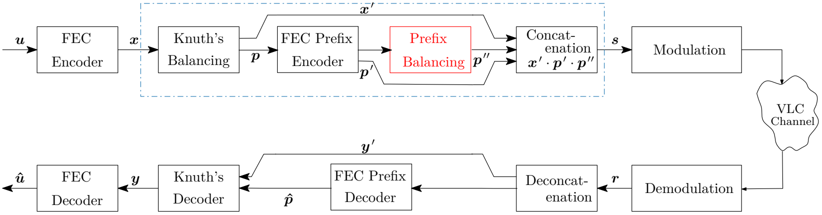


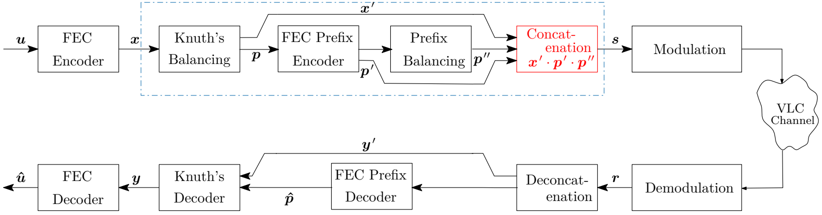
- Encode the prefix $PC(\boldsymbol{p}', \boldsymbol{p})$;
- The design of $PC(\boldsymbol{p}', \boldsymbol{p})$ is critical;

Proposed scheme



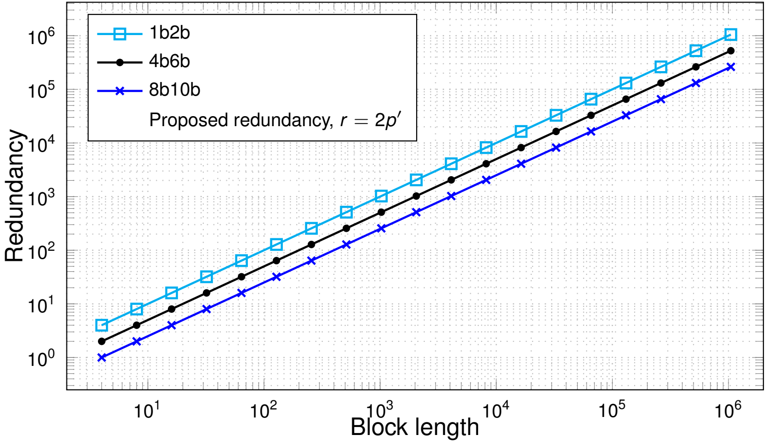
- Balancing the encoded prefix by appending $\boldsymbol{p}'$ complement;

Proposed scheme



- Assembling $\boldsymbol{x}'$, $\boldsymbol{p}'$ and $\boldsymbol{p}''$;

Redundancy comparison



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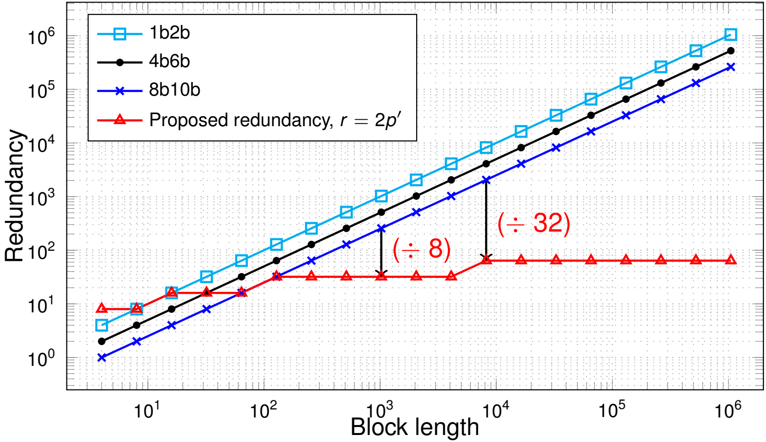

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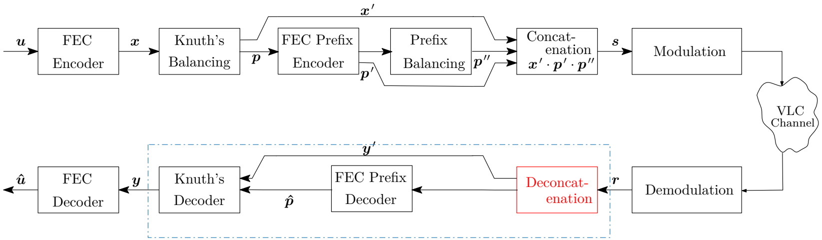
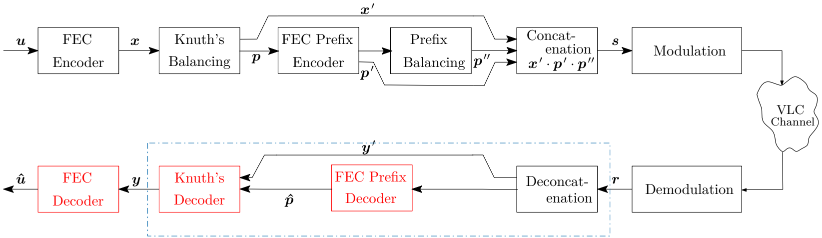


- De-concatenation $\boldsymbol{r} = \tilde{\boldsymbol{x}}' | \tilde{\boldsymbol{p}}' | \tilde{\boldsymbol{p}}''$;

Proposed scheme



- Successive cancellation (SC) to decode KA prefix;
- Then apply Knuth's decoder to recover $\boldsymbol{y}$;

FER analysis

- $P_e = P_{prefix} + (1 - P_{prefix})(P_{payload})$
- Given that $FER_{SC} = 1 - \prod_{i \in \mathcal{I}}(1 - p_i)$
- $FER = \left(1 - \prod_{i \in \mathcal{I}_2}(1 - \boldsymbol{Q}_i)\right) + \prod_{i \in \mathcal{I}_2}(1 - \boldsymbol{Q}_i) \cdot \left(1 - \prod_{i \in \mathcal{I}_1}(1 - \boldsymbol{Q}_i)\right)$

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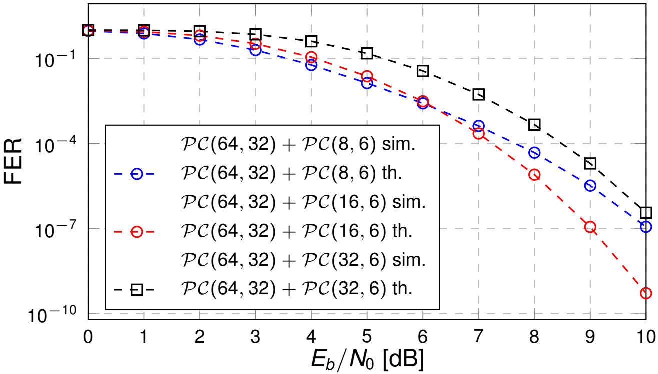

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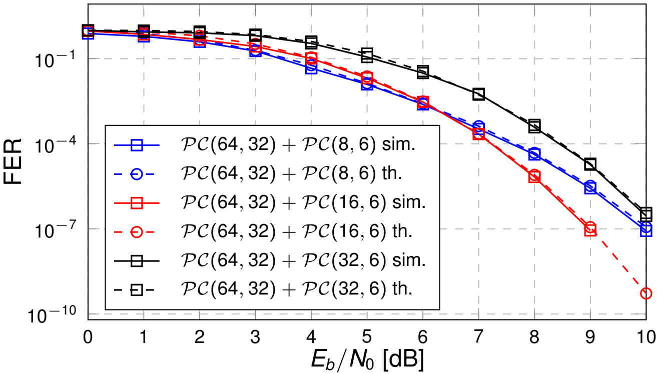
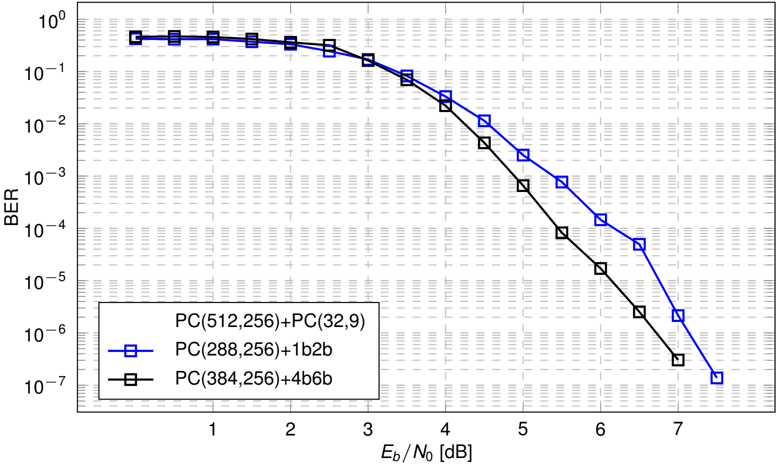


Comparison of various schemes at 50% dimming ratio with rate of 44%



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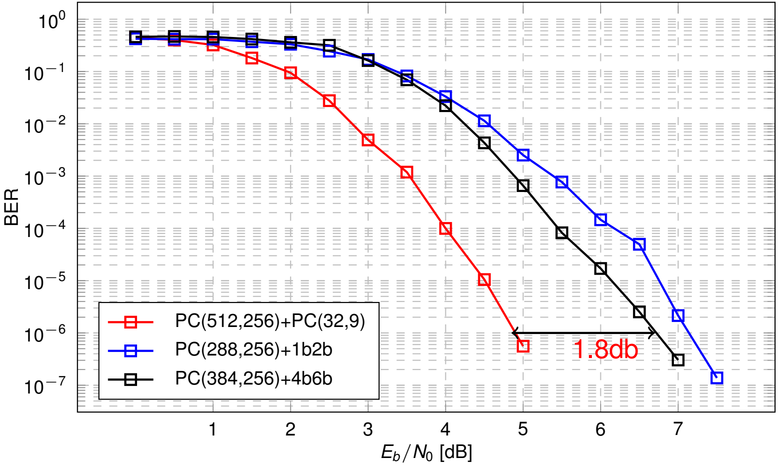

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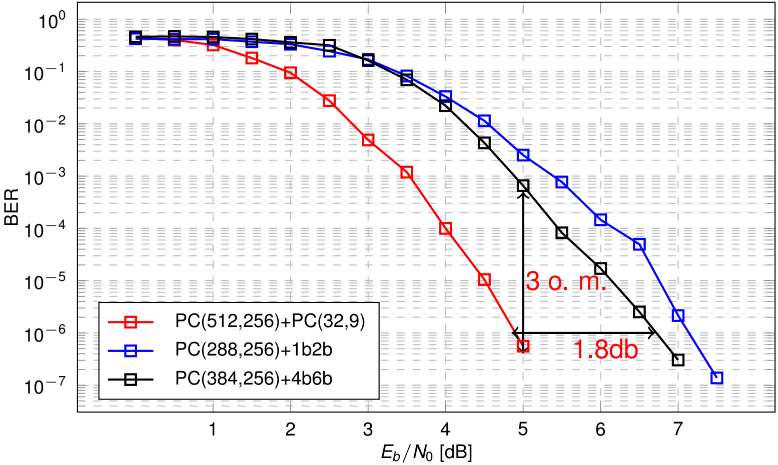

Transmission rates analysis

- K is the payload length
- R_1 and R_2, rates of the 1st and 2nd FEC
  - $R_2 = 50\%$ (Proposed scheme)

	Rates	$R_1 = 50\%$,	$R_1 = 75\%$
1b2b	$\frac{1}{2}R_1$	25%	37.5%
4b6b	$\frac{2}{3}R_1$	33.3%	50%
Proposed	$\frac{K}{\frac{1}{R_1}K+\frac{1}{R_2}\log_2 K}$	48.5%(K=256)	71.6%(K=256)
		49.5%(K=1024)	73.9%(K=1024)

Computational complexity analysis

- Number of operations required for decoding RLL codes and the proposed scheme for different rates with $K = 256$.
- Operation being any elementary calculation (add, sub, mult, exp, div)

	$R = 1/2$	$R = 1/4$
1b2b	288	556
4b6b	15744	30504
Proposed	704	1455

Conclusion

- Efficient scheme to generate flicker-free codes to mitigate light flickering at dimming of 50% was proposed based on KA
- 1.8dB better than compared schemes at a BER of 10^{-6} and rate of 44%
- Flexible transmission rates up to close R_1

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- 1.8dB better than compared schemes at a BER of 10^{-6} and rate of 44%
- Flexible transmission rates up to close R_1
- Future works includes:
  - extending this scheme for efficient dimming
  - further compression of the prefix length

End

THANK YOU !