Optimizing Optical Modulation with HSSK for IoT B5G Applications

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1. Introduction

Optical Camera Communication (OCC) offers a low-cost, energy-efficient alternative for IoT in 5G/6G networks by using visible light instead of RF signals, alleviating RF spectrum congestion. This work introduces Hue-Saturation Shift Keying (HSSK), a modulation scheme that encodes information in hue and saturation, simplifying symbol detection and removing the need for adaptive Region of Interest (ROI) tracking.

◈ HSSK Advantages for 5G/6G:
✓ Efficient use of the RF spectrum by enabling optical communication for IoT devices.
✓ Simplified implementation for LED-based systems.
✓ Robust performance for dense IoT networks in future 6G systems.

Tests at 5 meters showed that high symbol rates can cause undersampling, violating Nyquist-Shannon theory when symbols appear in fewer than two frames. Environmental interference and camera frame rate also impact detection, emphasizing the need for optimized synchronization.

2. Methodology

The developed OCC system consists of two main components: an RGB LED-based transmitter controlled by a microcontroller and a cell phone camera as a receiver, with offline data processing for symbol extraction and decoding.

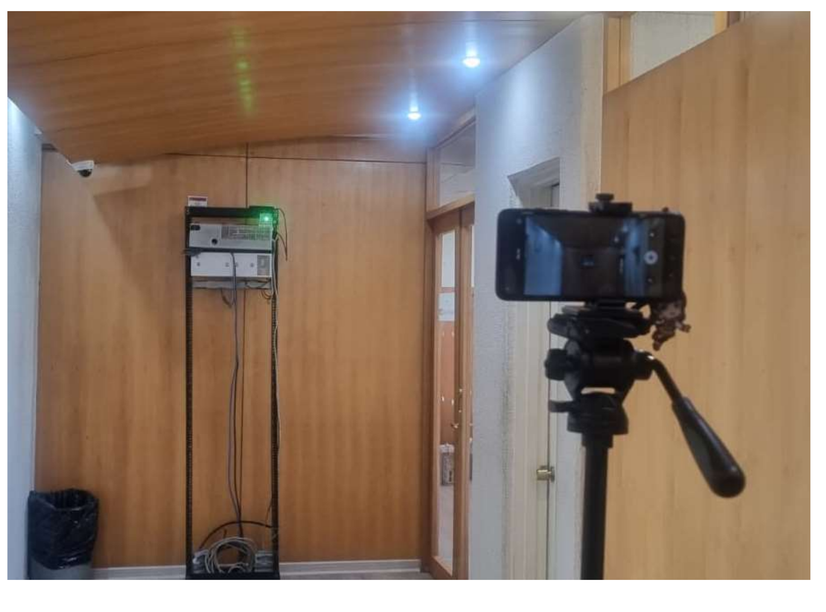

Fig. 1 - Transmission system setup at 5 meters, consisting of an RGB LED-based transmitter and a cell phone camera as the receiver.

2.1 Transmitter

- The transmitter is built around an ESP32 microcontroller, which controls an RGB LED to modulate information through hue and saturation variations. Each symbol is mapped to a unique hue-saturation pair, ensuring clear separation in the modulation space.
- Before data transmission, a synchronization signal is sent to allow the receiver to calibrate. Then, a cluster initialization signal helps adjust the symbol detection process. This method prevents brightness variations from affecting symbol recognition, improving robustness across different lighting conditions.

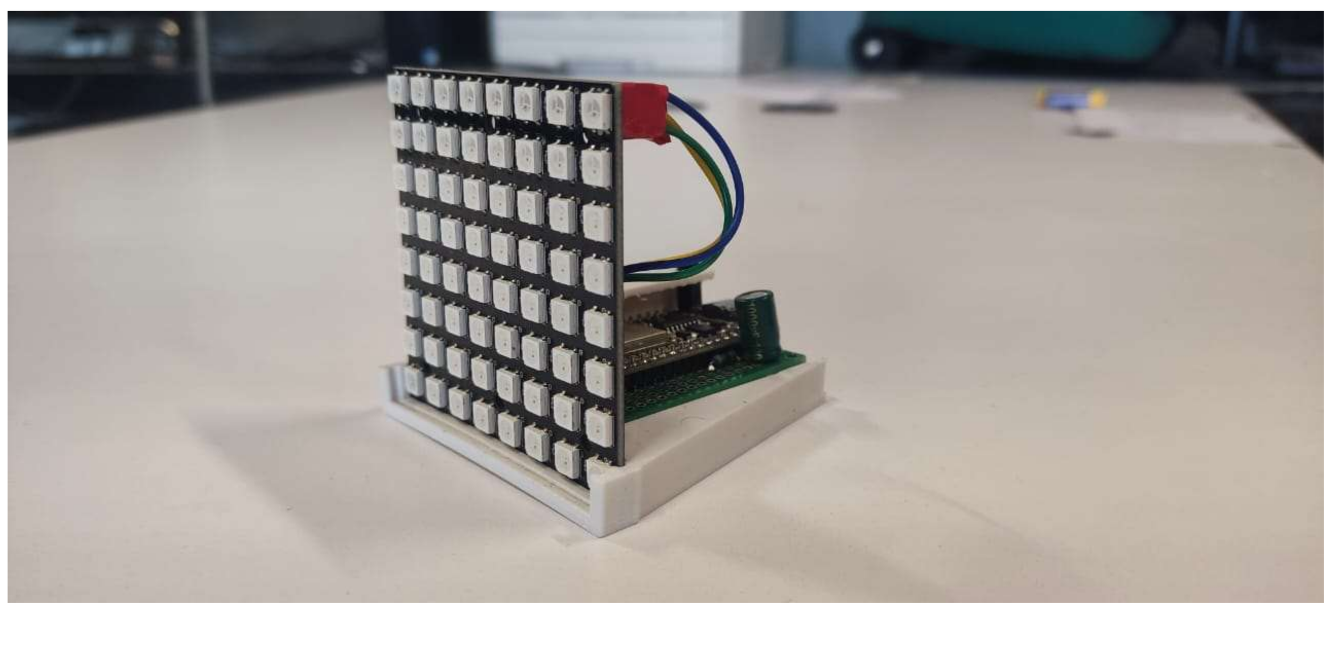

Fig. 2 - LED-based transmitter using a WS2812B RGB LED and an ESP32 microcontroller for Hue-Saturation Shift Keying (HSSK) modulation.

2.2 Receiver

- **Signal Capture**: The receiver captures the transmitted signal using a cell phone camera.
- **Video Processing**: The video is processed offline in MATLAB to extract hue and saturation values crucial for decoding.
- **Phase Compensation**: A phase compensation algorithm corrects timing mismatches caused by rolling shutter effects, ensuring proper alignment of detected symbols.
- **Channel Correction**: A channel correction algorithm reduces interference from external light sources and reflections, improving symbol detection accuracy and enhancing overall communication reliability.

2.2 Data Processing

- A Region of Interest (ROI) filter isolates the brightest non-white object in each frame for accurate symbol extraction. The extracted hue and saturation values are synchronized with a reference constellation, ensuring reliable data decoding. The system's performance is evaluated through Bit Error Rate (BER) analysis, examining how transmission speed affects detection accuracy.

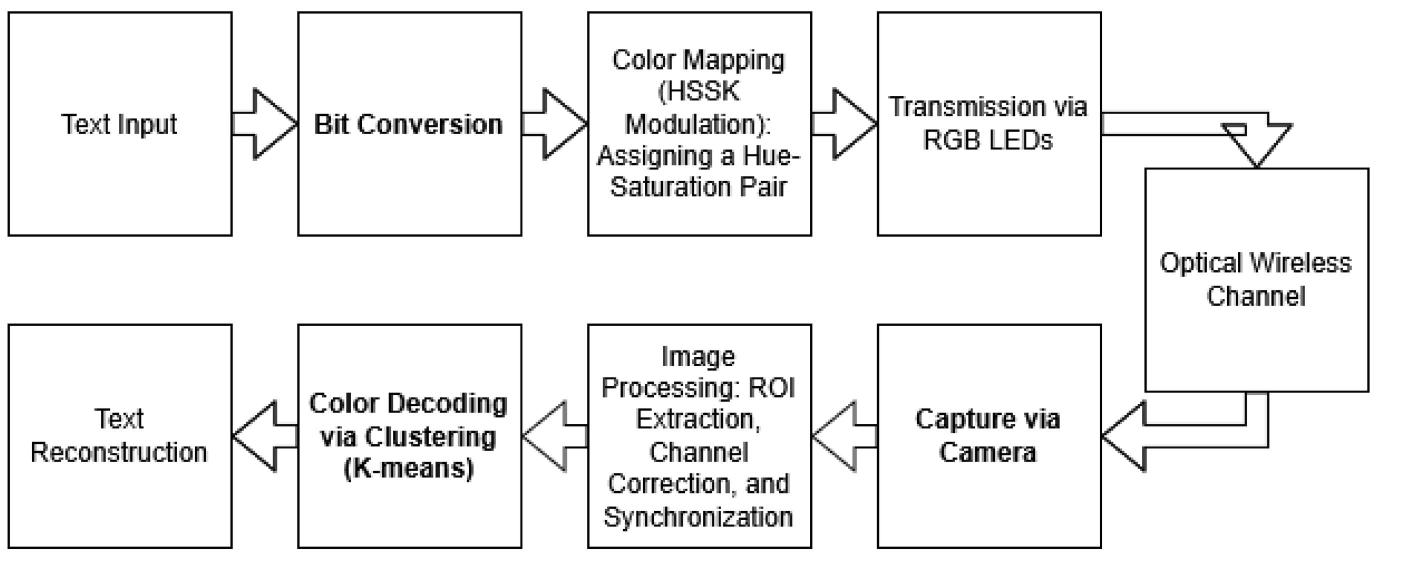

Fig. 3 – Block diagram illustrating the HSSK-based Optical Camera Communication (OCC) system, from text input to reception and reconstruction.

3. Preliminary Results.

Experiments conducted at 5 meters using 16HSSK evaluated the relationship between BER and transmission speed.

- At lower speeds, BER remains low, confirming stable communication.
- Increasing transmission speed introduces slight BER variations due to interference and the camera's sampling rate limitations.
- No critical impact due to undersampling was observed, but a practical limit was identified where symbol detection remains stable.

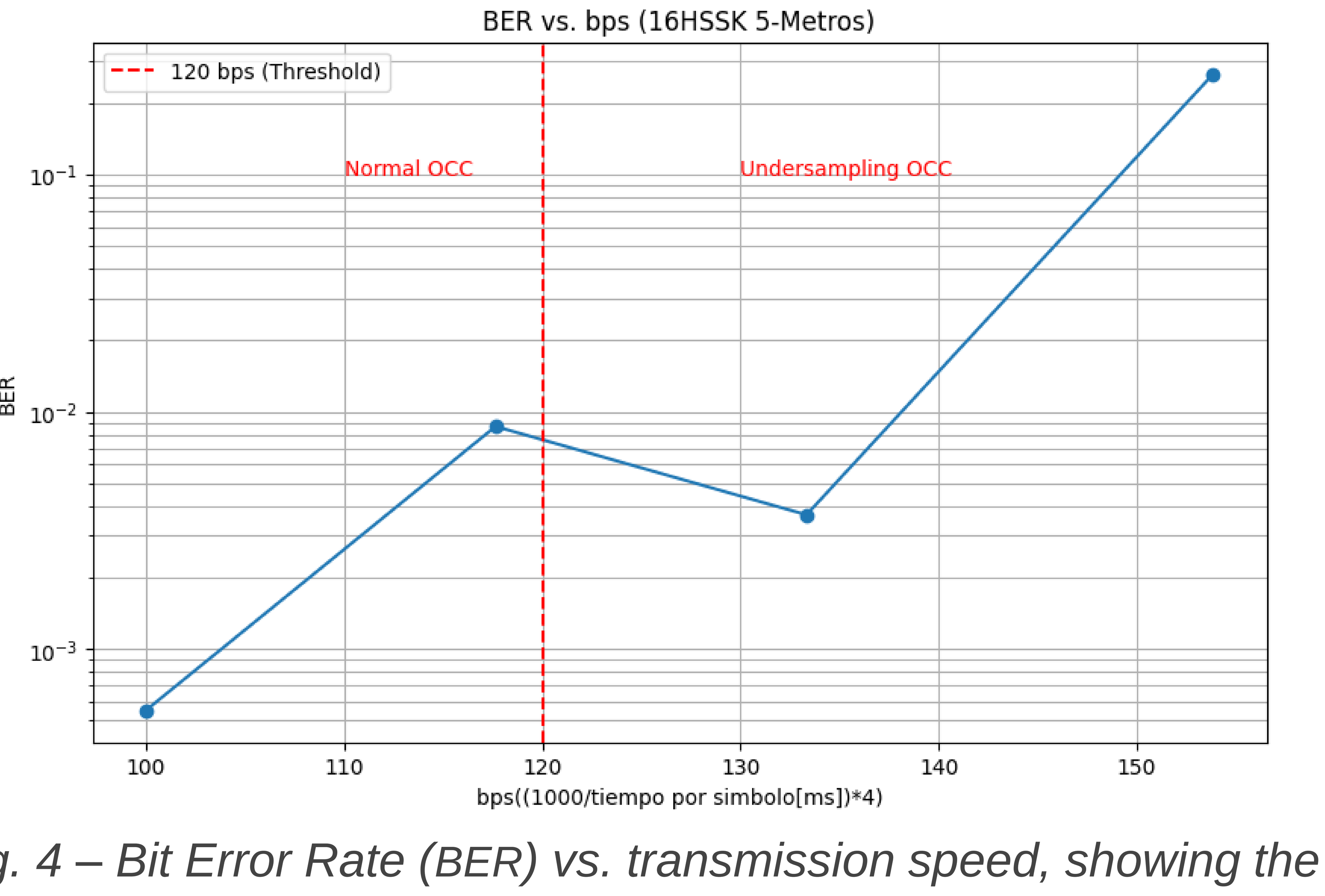

Fig. 4 – Bit Error Rate (BER) vs. transmission speed, showing the effect of increasing symbol transmission rate on system performance.

Summary / Conclusions

This work presents an OCC system using HSSK, offering a low-cost, scalable solution for IoT communication in 6G networks. By eliminating the need for RF connections, HSSK reduces spectrum congestion and enables more efficient communication for IoT devices.

Key Findings:

✓ Reliable communication with low BER, suitable for IoT in 5G/6G.
✓ Simplified system implementation compared to traditional CSK.
✓ Potential for creating more bandwidth in 6G by reducing RF reliance.

Future Work:

- Optimize synchronization for higher-speed symbol detection.
- Testing in diverse environments and lighting conditions.
- Explore AI/ML optimization for 6G IoT applications.
- Work on extending the system to longer distances

Bibliography or Website Project

- *[1] IEEE Standard 802.15.7 (2018). IEEE Standard for Short-Range Wireless Optical Communication Using Visible Light. IEEE Standards Association.*
- *[2]Ndjiongue, A. R., & Ferreira, H. C. (2020). APSK-CSK Systems Based on Kite and Color Wheel Constructions. IEEE Transactions on Communications, 68(10), 6075-6086. DOI: 10.1109/TCOMM.2020.3012356.*