Low-Complexity Visible Light Networking with LED-to-LED Communication

Domenico Giustiniano, Nils Ole Tippenhauer, Stefan Mangold


Visible Light Communication (VLC)

- VLC is an emerging technology,
  - it uses the visible light spectrum
  - light emitters (LEDs) transport information wirelessly
- VLC is a low-power, low-cost alternative to traditional short-range wireless RF communications

LED-to-LED communication

- Most of the research on VLC has focused on wideband white LEDs used in ambient illumination.
  - Wideband: 400 nm
- Narrowband and visible LEDs have received little attention.
  - Narrowband: 15 – 150 nm

Application: Toy-to-Toy Communication

1) Light is safe. 2) We can control the communication through the directivity and the visual field of light propagation → this makes it interactive (in contrast to infrared or RF).
Summary of the Rest of the Talk

- We investigate the limit of communication using a single LED and microcontroller (Arduino) for applications that require low PHY rate.
- We introduce an efficient MAC protocol to access the channel
  - CSMA/CA is here inefficient.
- We study and resolve the problem of light flicker.
  - Previous work does not consider that the light flicker when
    1. LEDs operates in ad-hoc network and
    2. the LED is also a receiver
- We implement and evaluate the solution in a network of up to four transceivers communicating on the same visible color.

Principles

- The brightness of LEDs can be adapted rapidly,
  - at speeds orders of magnitude higher than for conventional light emitting devices.
- By varying the intensity of the LED light source,
  - data messages can be communicated through visible light to a receiver sensitive to light.
  - In our approach, the receiver is the same LED used for transmission.
  - Only one microcontroller and one LED.

Transmission

- Station transmits the bits using the binary OOK modulation:
  
  bit = 0 → symbol = ZERO
  
  bit = 1 → symbol = ONE

Reception
Reception

\[ V_{ca}(T) > V_{th} \rightarrow \text{symbol} = \text{ZERO} \]
\[ V_{ca}(T) < V_{th} \rightarrow \text{symbol} = \text{ONE}. \]

Flicker transmitting data

Single light channel to transmit and receive data → flicker effects.

- Intra- and inter-data flickers

Data and Energy symbols

- Data symbols
  - Transmitter:
    - carry information (bit) from the transmitter to the intended receiver.
  - Receiver:
    - either receive any data from stations in range
    - or listen the channel before transmitting any data.
  - Only one station is allowed to output energy in each Data Symbol.

- Energy symbols
  - No data is transmitted.
  - Any station is free to output energy to the optical medium.
Flicker Elimination Scheme

symbol time $T$

(c) Data and Energy symbols. (d) Reception. (e) Transmitter, bit '10'.

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Visible Light Networking with LED-to-LED

Flicker Elimination

Time

Zero ONE ZERO ONE

Observed average

Flicker Region

No Flicker Region

1/(4CFF)

Using blue and red LEDs, we can transmit with symbol duration below $T = 1.5$ ms, without being affected by flicker and LED noise.

We use $T = 512$ $\mu$s unless otherwise stated.

Collision Detection Protocol

Transmission and Reception with One LED

Long time wasted in collisions due to low PHY rate $\rightarrow$

Key idea: sense the channel transmitting a ZERO symbol
Collision Detection Protocol

CSMA/CD MAC access protocol

Detection is possible at the transmitter using Data Symbols ZERO, where light can be sensed.

Two Contending LEDs

Three Contending LEDs

Data packet

- Software-based synchronization protocol.
- State machine for MAC protocol.
- All implemented in Arduino.
  - hex file of about 11 kB over the 30 kB available.
Collision Detection Protocol

Full flickering elimination

Data
ACK

ACK

Data

ACK

Rx

Rx

Rx

Rx

From renewal theory, the maximum system throughput $S_{\text{max}}$ is:

$$S_{\text{max}} = \frac{E[P]}{E[T_m]} = \frac{160}{352} \cdot \frac{T}{T} = 0.45/T$$  

For $T = 512 \mu s$, $S_{\text{max}} = 878 \, \text{b/s}$, very close to our experiments.

We obtain a Jain’s fairness index of $0.98 - 1$, that indicates that both our protocol and prototype implementation are fair.

CSMA/CD MAC Throughput

MAC Throughput

Conclusion

Short-range free-space LED-to-LED communication enables a wide variety of entertainment applications.

These applications benefit from:

- the explicit visual feedback to the user when pointing a device,
- the system simplicity and the low-cost nature of the LED-based systems.

We proposed and evaluated an LED-to-LED communication system,

- including physical layer transmission and networking protocols.

Our evaluation addressed technical challenges,

- such as the elimination of flicker and detection of collisions.