

# (In)visible Light Communication: Combining Illumination and Communication

Stefan Schmid<sup>Y§</sup>, Josef Ziegler<sup>§</sup>, Thomas R. Gross<sup>§</sup>, Manuela Hitz<sup>Y</sup>, Afroditi Psarra<sup>Y</sup>, Giorgio Corbellini<sup>Y</sup>, Stefan Mangold<sup>Y</sup>  
<sup>Y</sup> Disney Research Zurich, <sup>§</sup> ETH Zurich



Figure 1. a) Demo setup with off-the-shelf lamps, b) modified consumer light bulbs, c) toy car equipped with VLC technology

## 1. Internet of Light and Things

Consumer devices transform into interactive communication interfaces when visible light is used to transmit data. At home, during work or leisure time, light bulbs, toys, or other electronics and accessories can be used as environmental sensors, and act as user interfaces based on their location, play pattern, or other context provided by the Internet. Communication with light enables a true “Internet of Everything”.

Visible Light Communication (VLC) based on Light Emitting Diodes (LEDs) and low-cost off-the-shelf microcontrollers has been demonstrated [Corbellini et al. 2012]. LED-based lighting can be used for the Internet-of-Things and related wireless communication services by modulating the intensity of the emitted light. Further, LEDs can also be used as receivers just like photodiodes. The technology provides the foundation for ubiquitous networking using the visible light as communication medium. Such networks consist of consumer devices with LEDs and light bulbs that can also serve as access points (to connect to other networks) or as fixed points for localization.

The technology enables reliable communication over a distance of a few meters. LED-to-LED communication is a feasible solution to bring low-cost and non-complex connectivity to a large number of LED light bulbs and consumer devices [Schmid et al. 2012; 2013].

Using the visible light spectrum enables the combination of communication and illumination but makes it also possible to hide data exchange within lighting. Communication is independent from light effects or flickering that human eyes can perceive and data flow is visible and therefore steerable towards potential receivers.

## 2. Technology

The VLC technology employs off-the-shelf LEDs and LED light bulbs as communication front end. Reverse-biased LEDs can also act as light sensors and reduce the cost and complexity of VLC devices. The software-based physical and medium access control layer running on top of low-cost microcontrollers introduce a

flexible communication framework and enable shared medium access for network scenarios while keeping light output constant to avoid flickering.

## 3. Communication Protocols

The technology is based on three layers: The physical (PHY) layer is responsible for turning data into light used for illumination and communication. The Medium Access Control (MAC) layer handles the access to the communication medium (light) to support a network of devices. On top of these two layers runs the application layer that is specific for every use case.

### 3.1 PHY Layer

The PHY layer is responsible for illumination and communication. Light slots (during which light can be emitted) and reception slots (during which no light is emitted and light signals can be received) are alternating to provide constant brightness during transmission and reception of data. The level of brightness can be dynamically adapted by changing the number of light slots where light is emitted.

### 3.2 MAC Layer

The MAC layer employs a Wi-Fi-like contention-based approach. The reception of each data frame is confirmed with an acknowledgment (ACK) frame. If the ACK is missing, the last data frame is immediately retransmitted. To reduce the probability of collisions in a multi-device network, before transmitting the data, each device waits for a contention window of random length. During this time, the device scans the medium and if activity is detected, it defers until the ongoing transmission is done.

## References

- CORBELLINI G., SCHMID S., MANGOLD S., GROSS T.R., AND MKRTCHYAN A. 2012 LED-to-LED Visible Light Communication for Mobile Applications. In Demo at ACM SIGGRAPH Mobile.
- SCHMID S., CORBELLINI G., MANGOLD S., AND GROSS T.R. 2013. LED-to-LED Visible Light Communication Networks. In ACM MobiHoc, 1-10.
- SCHMID S., CORBELLINI G., MANGOLD S., AND GROSS T.R. 2012. An LED-to-LED Visible Light Communication system with software-based synchronization. In Optical Wireless Communication. Globecom Workshops, 1264-1268.

# (In)visible Light Communication: Combining Illumination and Communication

Stefan Schmid<sup>Y§</sup>, Josef Ziegler<sup>§</sup>, Thomas R. Gross<sup>§</sup>, Manuela Hitz<sup>Y</sup>, Afroditi Psarra<sup>Y</sup>, Giorgio Corbellini<sup>Y</sup>, Stefan Mangold<sup>Y</sup>  
<sup>Y</sup> Disney Research Zurich, <sup>§</sup> ETH Zurich



Figure 1. a) Demo setup with off-the-shelf lamps, b) modified consumer light bulbs, c) toy car equipped with VLC technology

## 1. Internet of Light and Things

Consumer devices transform into interactive communication interfaces when visible light is used to transmit data. At home, during work or leisure time, light bulbs, toys, or other electronics and accessories can be used as environmental sensors, and act as user interfaces based on their location, play pattern, or other context provided by the Internet. Communication with light enables a true “Internet of Everything”.

Visible Light Communication (VLC) based on Light Emitting Diodes (LEDs) and low-cost off-the-shelf microcontrollers has been demonstrated [Corbellini et al. 2012]. LED-based lighting can be used for the Internet-of-Things and related wireless communication services by modulating the intensity of the emitted light. Further, LEDs can also be used as receivers just like photodiodes. The technology provides the foundation for ubiquitous networking using the visible light as communication medium. Such networks consist of consumer devices with LEDs and light bulbs that can also serve as access points (to connect to other networks) or as fixed points for localization.

The technology enables reliable communication over a distance of a few meters. LED-to-LED communication is a feasible solution to bring low-cost and non-complex connectivity to a large number of LED light bulbs and consumer devices [Schmid et al. 2012; 2013].

Using the visible light spectrum enables the combination of communication and illumination but makes it also possible to hide data exchange within lighting. Communication is independent from light effects or flickering that human eyes can perceive and data flow is visible and therefore steerable towards potential receivers.

## 2. Technology

The VLC technology employs off-the-shelf LEDs and LED light bulbs as communication front end. Reverse-biased LEDs can also act as light sensors and reduce the cost and complexity of VLC devices. The software-based physical and medium access control layer running on top of low-cost microcontrollers introduce a

flexible communication framework and enable shared medium access for network scenarios while keeping light output constant to avoid flickering.

## 3. Demos

The contribution consists of two main demos. The first involves VLC enabled consumer light bulbs, smartphones and smart toys communicating with each other. The second presents a dress equipped with LEDs that can receive and react to incoming light messages.

### 3.1 Light Bulbs, Smartphones, and Smart Toys

The VLC-enabled light bulb is used in an off-the-shelf lamp. The light bulbs broadcast text that is received and displayed by a smartphone. The smartphone uses a device plugged into the smartphone’s audio jack to forward light readings to the running application. Further, the light bulbs can also trigger different light and sound effect in toy cars.

The smartphone application can also send messages to the toy cars using the audio jack device which can then relay the received information to other toy cars and also back to the smartphone itself.

### 3.2 Dress

Magic wands with an LED as tip trigger different lighting patterns on an LED-equipped dress. Since every LED is able to receive messages, the wands can be used to “draw” on the dress or the LED receiving the trigger message can indicate the starting point of a light effect. Multiple patterns can be started by different wands, sending different messages, to show data communication.

## References

- CORBELLINI G., SCHMID S., MANGOLD S., GROSS T.R., AND MKRTCHYAN A. 2012 LED-to-LED Visible Light Communication for Mobile Applications. In Demo at ACM SIGGRAPH Mobile.
- SCHMID S., CORBELLINI G., MANGOLD S., AND GROSS T.R. 2013. LED-to-LED Visible Light Communication Networks. In ACM MobiHoc, 1-10.
- SCHMID S., CORBELLINI G., MANGOLD S., AND GROSS T.R. 2012. An LED-to-LED Visible Light Communication system with software-based synchronization. In Optical Wireless Communication. Globecom Workshops, 1264–1268.