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Source: [(1) Dominic O'Brien, Hoa Le Minh (2) Olivier Bouchet (3) Sebastian Randel,,
Joachim Walewski (4) Klaus-Dieter Langer, Jelena Grubor (5) Jose A. Rabadan Borges, Rafael Perez Jimenez]
Company [(1) University of Oxford (2) France Telecom (3) Siemens Corporate Technology,Information and Communications (4) Fraunhofer, Heinrich-Hertz-Institute (5) ETSIT Universidad de Las Palmas de Gran Canaria]
Address []
Voice:[], FAX: [], E-Mail:[(1) dominic.obrien@eng.ox.ac.uk, Hoa.le-minh@eng.ox.ac.uk (2) olivier.bouchet@orange-ftgroup.com (3) sebastian.randel@siemens.com (4) langer@hhi.fraunhofer.de, grubor@hhi.fraunhofer.de (5) jrabadan@dsc.ulpgc.es, rperez@dsc.ulpgc.es]

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Abstract: [VLC offers capacity augmentation in simple broadcasting and potential for very high speed optical links over short distance. It features small cell sizes, intuitive security, and intuitive pointing.]

Purpose: [Contribution to IEEE 802.15 IG-VLC]

Visible Light communications: A European perspective

Dominic O'Brien, University of Oxford, dominic.obrien@eng.ox.ac.uk

Hoa Le Minh, University of Oxford, Hoa.le-minh@eng.ox.ac.uk

Olivier Bouchet, France Telecom, olivier.bouchet@orange-ftgroup.com

Sebastian Randel, Siemens Corporate Technology,Information and Communications, sebastian.randel@siemens.com

Joachim Walewski, Siemens Corporate Technology, Information and Communications, joachim.walewski@siemens.com

Klaus-Dieter Langer, Fraunhofer, Heinrich-Hertz-Institute, langer@hhi.fraunhofer.de

Jelena Grubor, Fraunhofer, Heinrich-Hertz-Institute, grubor@hhi.fraunhofer.de

Jose A. Rabadan Borges, ETSIT Universidad de Las Palmas de Gran Canaria, jrabadan@dsc.ulpgc.es

Rafael Perez Jimenez, ETSIT Universidad de Las Palmas de Gran Canaria, rperez@dsc.ulpgc.es

Overview

- Introduction
- Technical overview
- Research in Europe
- VLC community
- Future developments

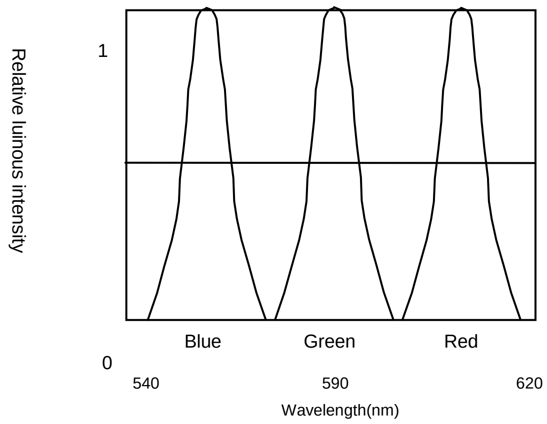
Introduction: the lighting landscape

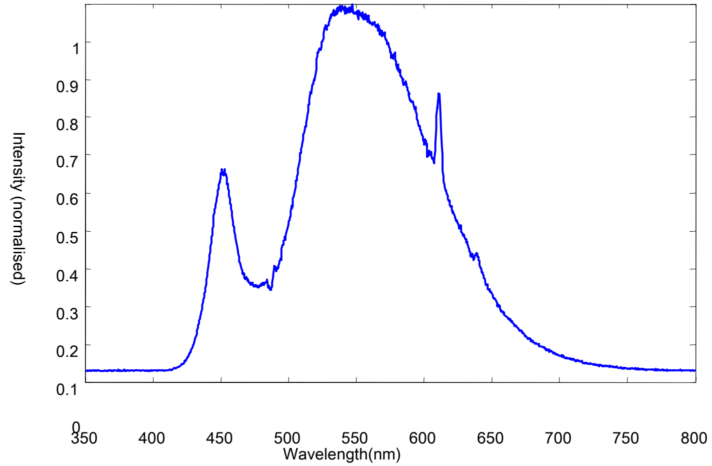
- Domestic
  - Mostly incandescent/compact fluorescent
  - Some LED lamps available
  - 18 TWh/annum used in UK [1]
    - Potential for 3TWh/annum with total conversion to 100 lumen/W LED
- Commercial
  - Fluorescent, and vapour lamps (48TWh/annum in the UK)
    - Increasing interest in sensor-based control
      - DALI (digital addressable lighting interface) bus used to communicate between sensors and dimming ballasts
      - Wireless networks using Zigbee etc. to control lights, with possibility of self-power

[1] 'Light emitting diodes: eco-design innovation roadmap', UK Market Transformation Programme,2005, available for download from www.mtprog.com

Technical overview: sources

- Two types of LED
  - RGB triplet devices
  - Single chip+ phosphor devices
- Typically driven with several 100mA at 2.5–3V, producing 100mW optical power

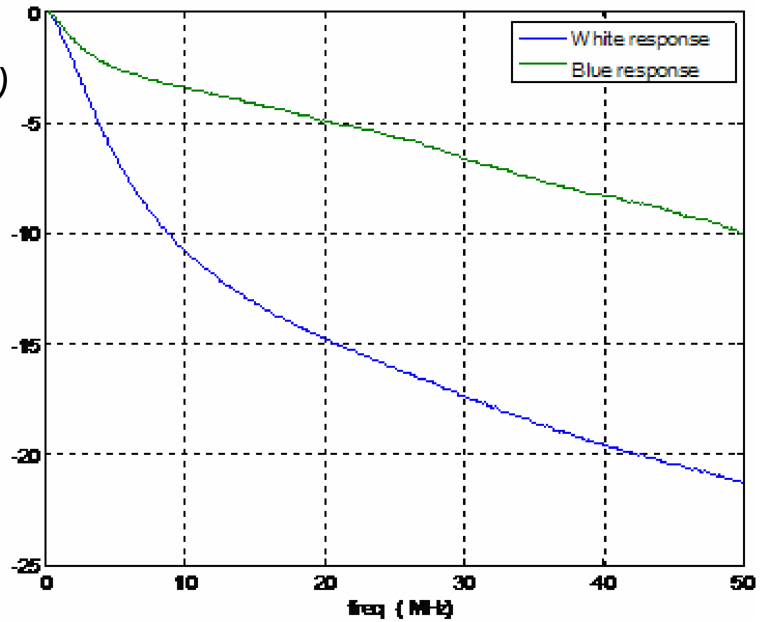


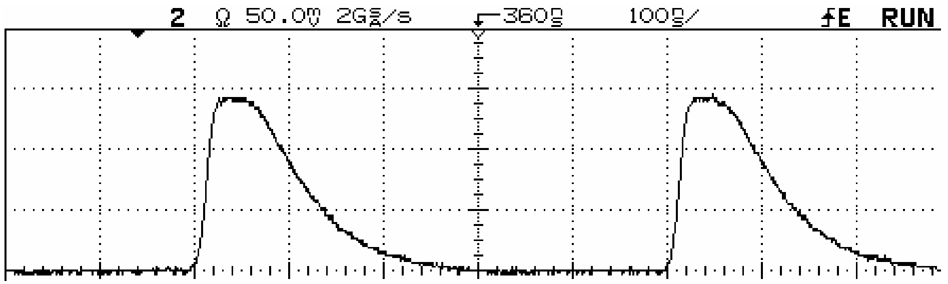


Technical overview: sources

- Modulation bandwidth
  - Dependent on device type
  - Typically 1–3MHz for 'whole' spectra

Normalised response (dB)





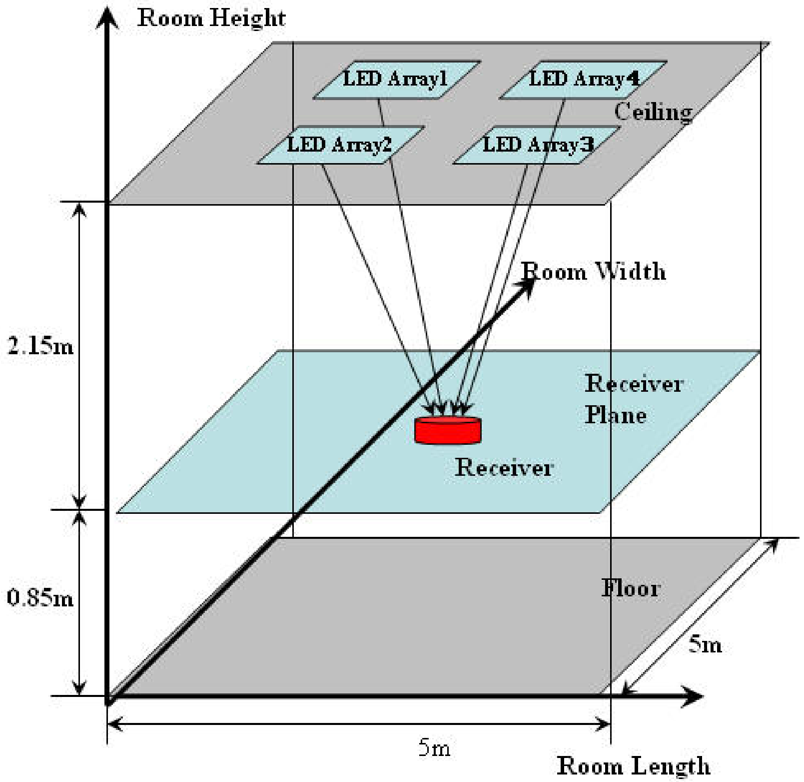
White-light response of Luxeon star device

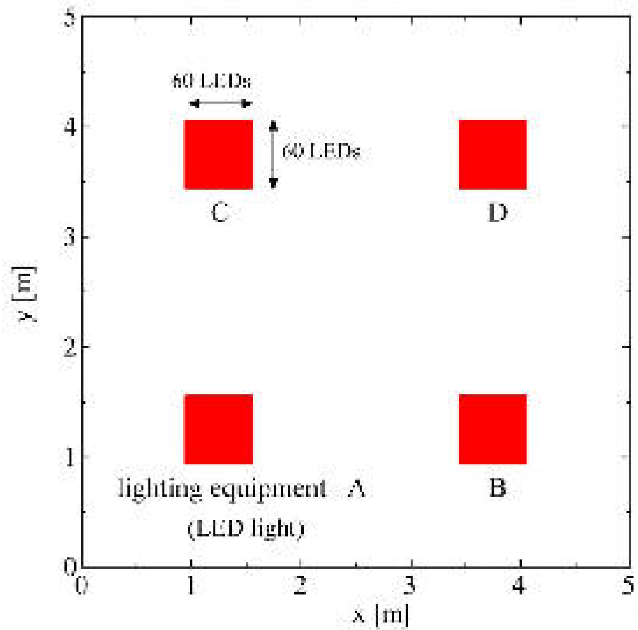
to short pulse

Frequency response of white and blue components-Luxeon star

Measurements from the University of Oxford

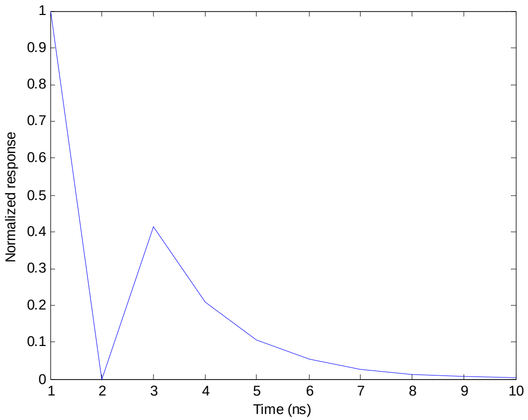
Technical overview: channel





Technical overview: Channel

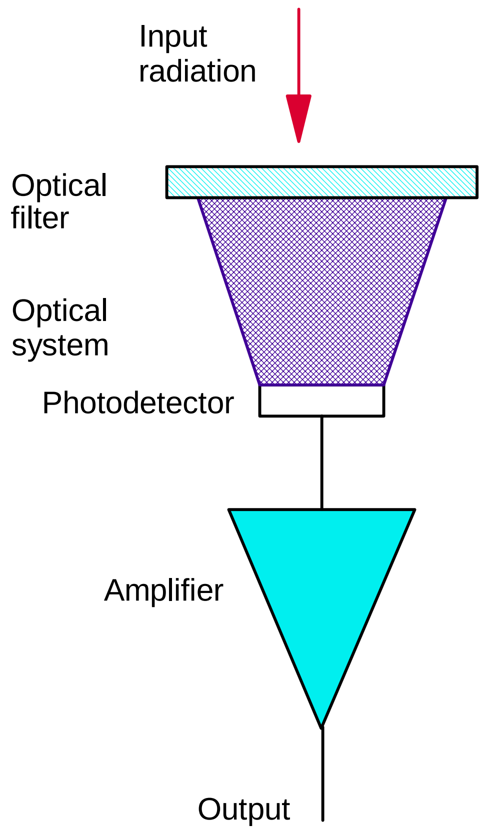
- Two propagation paths
  - Line of sight
    - Strong paths calculated using the illumination patterns from LED arrays
  - Diffuse
    - Modelled by assuming the room is equivalent to an integrating sphere
- Channel impulse response calculated for each point in the room



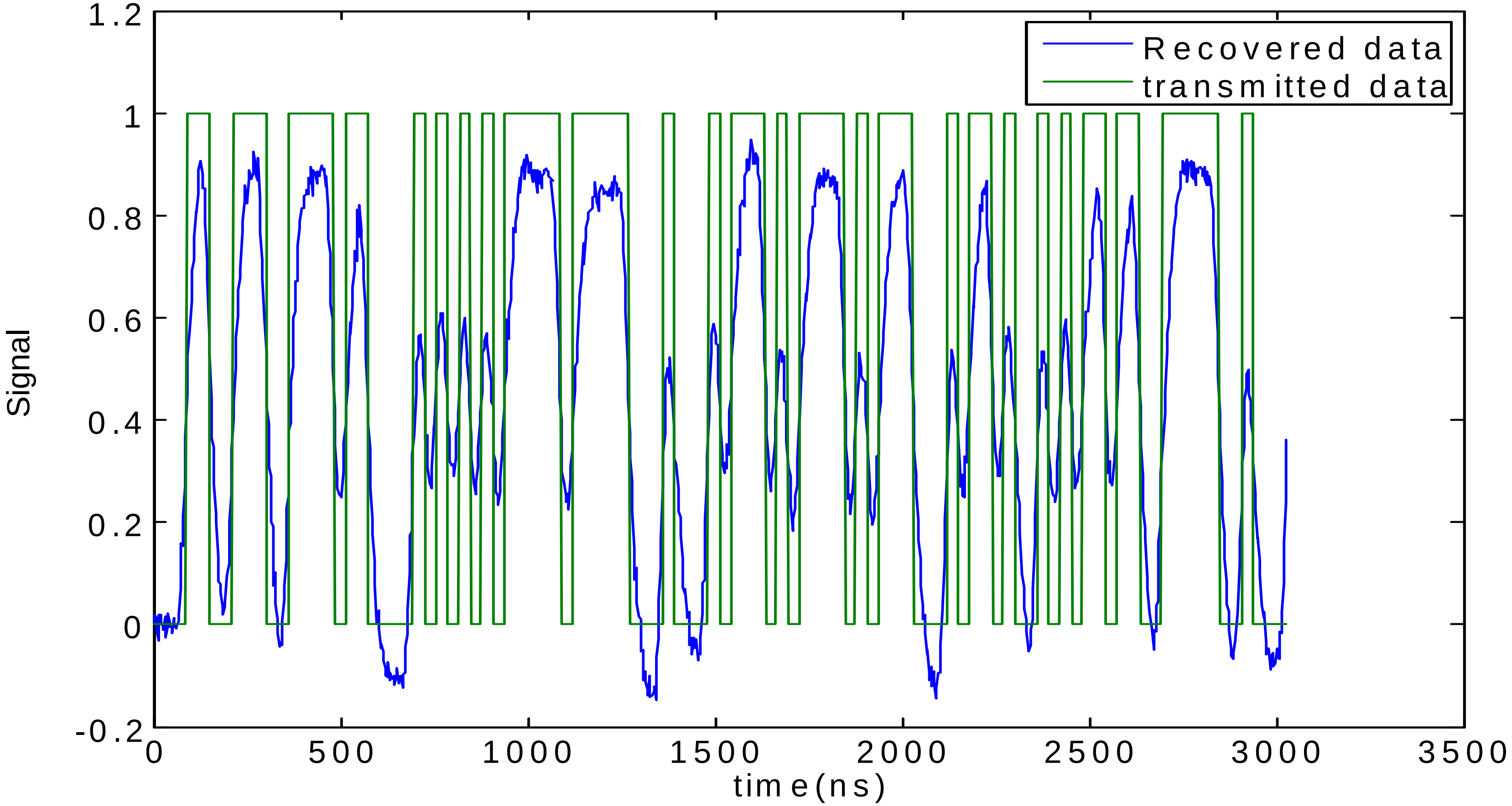
Typical impulse response

Technical overview: Receiver

- Receiver
  - Optical filter
    - Rejects 'out-of-band' ambient illumination noise
    - Removes slow yellow component
  - Lens system or concentrator
    - Collects and focuses radiation
  - Photodetector (or array of detectors)
    - Converts optical *power* to *photocurrent*
      - Incoherent detection
  - Preamplifier
    - Determines system noise performance
  - Post-amplifier and subsequent processing

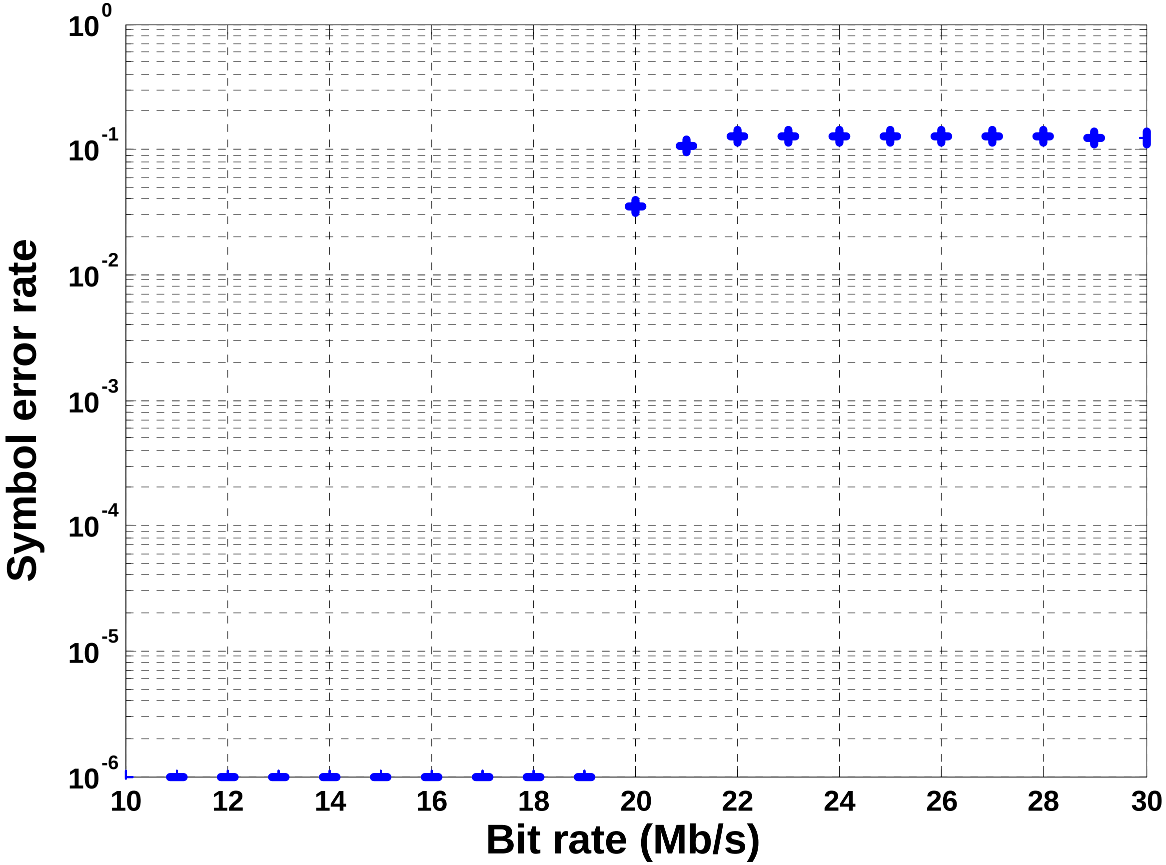


Link simulation:typical results



Data rate 33Mb/s

BER performance



BER for NRZ data transmission (unequalised)

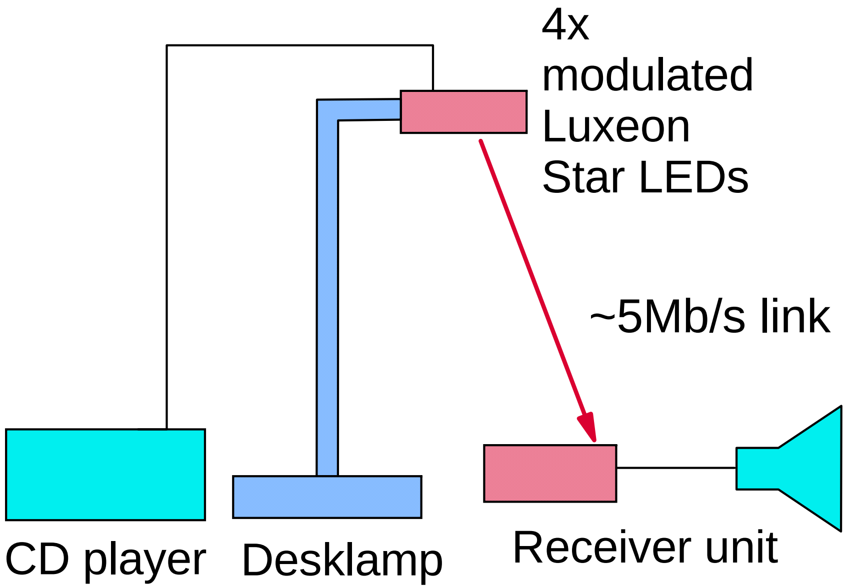
Attributes of VLC

- Security
- Low complexity
- Aesthetics
- Potential of short range 'point and shoot'
- Immunity to RF electro-magnetic interference (EMI)
- Directivity and an intrinsically small cell size (femtoc ells, shielding by opaque surfaces) offering spatial r euse opportunities
- High SNR due to high lighting level
- Dual use of lighting ("zero"-CAPEX & -OPEX data tr ansmission as compared to lighting-only scenarios)
- No e-smog

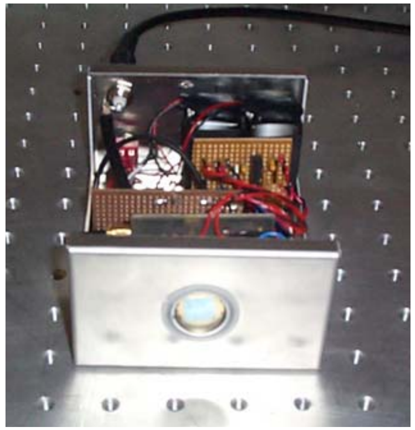
Systems results

- Data rate
  - 40Mb/s NRZ over very short distances (Fraunhofer, Heinrich-Hertz-Insitute)
    - 20MHz bandwidth
    - Implies 100Mb/s DMT
    - Simulations show feasible over longer ranges in typical lighting scenarios
  - ~40Mb/s over several metres (University of Oxford)
- Broadcasting
  - CD broadcast using 5-6Mb/s VLC link (University of Oxford)

Music broadcast demonstrator




Transmitter


Receiver

Music demonstrator fabricated at University of Oxford

VLC: European research

- Growing interest in Europe
  - Groups including
    - Siemens, Fraunhofer,Heinrich Hertz Institute, University of Las Palmas de Gran Canaria , France Telecom, University of Oxford
  - Completed EU project 'ISLE' with car to car communications usin g LED lamps
  - EU project 'OMEGA' with Optical Wireless communications under way
- Wireless World Research Forum
  - Working towards VLC whitepaper (completion in April 2008)
  - Possible book on VLC
    - Contributions solicited, particularly from solid state lighting industry
    - (email dominic.obrien@eng.ox.ac.uk)

Challenges: Technical

- Modulation bandwidth
  - DMT (requires linear LED drivers)
  - Modification of device structure
  - Link equalisation
- PWM illumination control
  - Gaps in transmission waveform
  - Noisy electrical waveform from DC converter circuitry
- Provision of an uplink
  - Cooperative optical and RF wireless
- Provision of higher network layers
  - Little work as yet

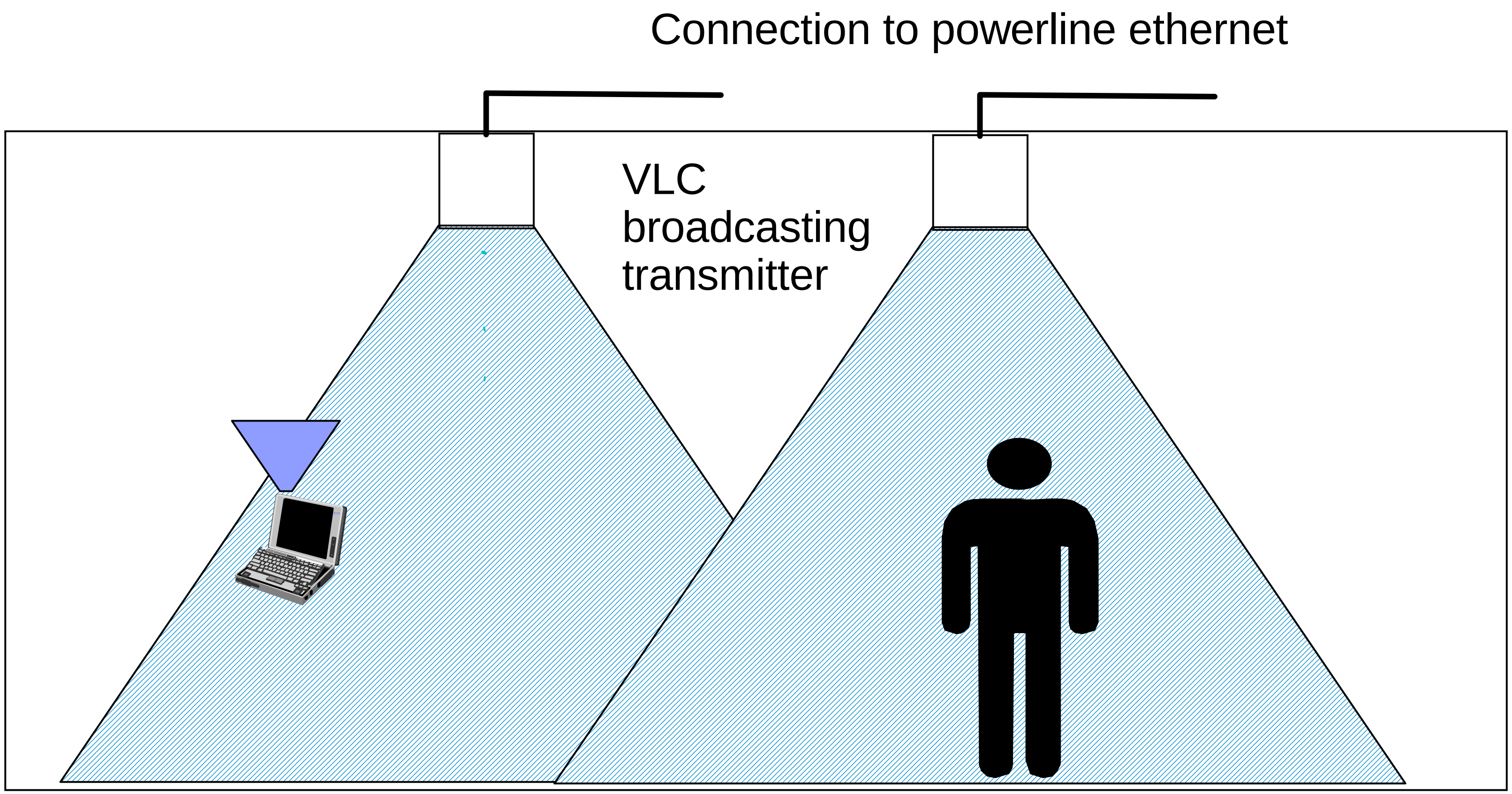
Challenges: standardisation

- Need to consider other standards
  - Illumination
    - Levels, control mechanisms
    - PLC etc
- Advantage
  - New field and not so many ‘vested interests’

Possible targets for standardisation

- Local broadcasting
  - Unidirectional
  - Demonstrations and simulations of 40Mb/s NRZ (100Mb/s wit h signal processing)
  - Digital TV multiplex (several)
  - Radio spectrum resource saved for bidirectional shared chan nel communications
- Very high speed data links
  - Visibility offers easy alignment and better link budget
  - Sub 1 metre could be more efficient than UWB and/or IRDA

Possible broadcasting scenario



Conclusions

- VLC offers
  - Capacity augmentation and simple broadcasting
  - Potential for very high speed optical links over short distance
  - small cell sizes
  - intuitive security
  - intuitive pointing
- Next steps
  - Representatives of lighting community
  - System designs
    - VLC broadcast
      - Progress in link data rates
    - High-speed link
      - Basic work still required for good comparison with other technologies