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Abstract: [VLC has a number of technical challenges, which are discussed in the presentation]
Purpose: [Informing those interested in VLC of some of the technical challenges faced]
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Some Challenges for Visible Light Communications

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Introduction

• Typical VLC link characteristics
• Challenges
  – Technical
    • Bandwidth limitations
    • Providing an uplink
  – Regulatory
    • Compatibility with Lighting Control systems
    • Illumination systems
• Conclusions
Typical link characteristics

- Source
- Channel
- Receiver
LED Modulation

• Opto-electronic response

![SPICE Model](image)

*Luxeon LED*

\[ R_s = 0.9727 \, \Omega \]
\[ L = 33.342 \, \text{nH} \]
\[ C_s = 2.8 \, \text{nF} \]
\[ C_d = 2.567 \, \text{nF} \]
\[ \tau_t = 1.09 \, \text{ns} \]

![Relative response](image)

*Measured LED small-signal bandwidth*
Improvement of LED Response

• Using blue-response only (blue filtering)

Measured optical spectrum

Measured impulse response

• Issue: Only 10% of signal power is recovered
  ⇒ Reducing SNR, link distance
• LEDs with more blue energy [1] could be used to gain more filtered power, however the balance of white colour is shifted

VLC Channel
Room Power Distribution

• Assume
  – 1% modulation of typical illumination power
  – Typical receiver performance

• Conclusions
  – Very high SNR available
    • SNRmin = 38.50dB
    • SNRmax = 49.41dB
  – Modulation limited by source bandwidth
Optical Receiver

- Receiver consists of
  - Optical filter
    - Rejects ‘out-of-band’ ambient illumination noise
  - Lens system or concentrator
    - Collects and focuses radiation
  - Photodetector (or array of detectors)
    - Converts optical power to photocurrent
      - Incoherent detection
  - Preamplifier (or number of preamplifiers)
    - Determines system noise performance
  - Post-amplifier and subsequent processing
Optical Receiver: Constant Radiance Theorem

- Optical ‘gain’ of receiver limited by required field of view

\[ A_i \Omega_i \leq A_o \Omega_o \]

\[ A_i \Omega_i \leq A_o 2\pi \]
Receiver Performance: Figure of Merit

• Receiver Figure of Merit (FOM)
  – Fibre systems
    • Performance determined by sensitivity (given sufficient detector area)
    • FOV usually not relevant
  – Free space systems
    • Etendue crucial determinant

\[
FOM = \frac{2 \pi R_b A}{P_{\text{min}}}
\]
Improving data rate: equalisation

• Transmitter equalisation
  – High bandwidth
  – Energy efficiency

• Blue filtering
  – Lose low frequency energy from phosphor

• Receiver
  – Simple analogue equalisation
  – More complex also
Typical waveforms for RX equalisation

Data rate 33 Mb/s

Data rate 14 Mb/s

NRZ data

Manchester data
Bandwidth Improvement: Post Equalisation

- Pre- and post-equalization: single LED link
Improving data rate: complex modulation

• High SNR channel
  – Complex modulation attractive

• OFDM
  – 100Mb/s over 20MHz channel [1]

• PAM
  – Simulations show LED characteristics not optimal

Improving data rate: PAM

- Simulation uses measured LED impulse response
- Simple 1\textsuperscript{st} order RX equaliser
- 4-PAM
- 24Mb/s (33Mb/s NRZ)

Further work required
Improving data rate: MIMO

- Parallel ‘alignment free’ data links
- Simulations show linear capacity growth
- Experimental results for a simple IR system
- Simulations of in-room VLC system
Simple IR system

Experimental system

Channel 1

Channel 2

Recovered data

Transmitted data
MIMO VLC: Simulation System

Room Height

LED Array

LED Array

LED Array

LED Array

Ceiling

Room Width

2.15m

Receiver Plane

Receiver

Floor

0.85m

5m

Room Length

5m
MIMO VLC: Preliminary Results

Aggregate data rate is linearly proportional to the number of channels and channel rate.
Providing an uplink

- VLC good at broadcast
- Uplink difficult to achieve
  - Retro-reflectors
    - Low speed
    - Low cost
  - IR uplink
    - Separate system
    - Infrastructure complex and expensive
Retro-Reflecting Link

- Novel optical communications between reader and tag
- Low power (tag has no source)
- Long range (determined by illumination source)
- Visibly secure (user can see beam of light)
Cooperative communications

Providing an uplink: Cooperative systems

- Combine VLC with RF
- Optical downlink only
- RF uplink/downlink
  - 100Mb/s downlink/10Mb/s RF LAN
  - Fuzzy logic decision making
  - Typical traffic asymmetry
  - Significant performance benefits using combination

Compatibility with lighting

- Most modern systems use PWM dimming
  - Channel does not exist when light is dimmed

- Solutions
  - Use modulation scheme that ‘incorporates’ PWM dimming (PPM-like)
  - Use sensing to only transmit in active regions
  - But both reduce overall data rate

- Requirement for closer collaboration with lighting industry.
Conclusions

• VLC offers high SNR low bandwidth channel
  – Naturally suited to broadcast

• Challenges
  – Data rate
  – Uplink
  – Compatibility

• If overcome possibility of low cost method to augment wireless capacity