The Future of VLC: Potential and Limitations

Prof. Maite Brandt-Pearce
Optical Communications
What technical, political and economic factors led to the widespread deployment and use of fiber-optics?
Fiber-optics ...

- Promised to (eventually) hugely expand upon the capability of current systems
- Replaced technology that is fundamentally limited with another that is merely technologically limited.
- Used revolutionary approach instead of being evolutionary
- Offered service that was previously entirely unavailable and thus had no market
- Required a considerable investment in infrastructure

... sound familiar?
Recipe for Adoption of New Technology

- Technical benefits of significant scale – game changing
- Consumer demand for improvement:
  - Cost
  - Service
  - Perceived environmental impact
  - Coolness factor
- Cost-point must be highly competitive compared with established solutions
- Coexistence/synergy with big-boys in industry (in lighting and comm)
Visible Light Communications

- **Goal:** Use the lighting system also for communications
- **Why:** 80% of wireless data communication today is indoors, and Wi-Fi can’t keep up.

- Transmission requires energy, yet energy is already going from infrastructure to user in the form of light.
Limitations and Opportunities

- Transmitters
- Information rates
- Shadowing
- MAC layer and multiuser access
- Uplink technology

- Uplink technology
- Backhaul
- Convergence
- Lighting features
- Applications

Let’s fix the technical issues so the marketing guys can run with it and make all the money …
Sources Not Designed for Comm.

LEDS ...
- Ubiquitous
- Noncoherent and easy to modulate
- Bandwidth limited to few MHz
- Tri-band offers $\lambda$ multiplexing

Luminaries ...
- So much potential, but how do we access it easily and cheaply?
Improving Information Rates

- Hardware – new µLEDS
- Transmitter processing
  - Modulation and Coding
  - Pre-equalization
- Receiver processing
  - Imaging receivers
  - Equalization
- MIMO
  - Is there a possibility of significant multiplexing gain?
Modulation

- **Issues:**
  - Flicker
  - Dimming
  - LED rise-time
  - LED nonlinearity

- **Options:**
  - Pulse-based (MEPPM)
  - Multicarrier (OFDM)
Shadowing

- Need a magical “Peter Pan Algorithm”
- Schools of thought:
  - Overprovision and over-light so there is no shadow
  - Use VLC as an enhancement when available.
- Or ... use adaptive modulation and coding to adjust to channel changes
- Key: fast accurate channel estimation

Jungnickel, 2014
Multiuser Access

- Frequency, time, and code division, as usual for optical comm.
- More interesting: space division multiple access, with significant spatial reuse
- Optimized LED modulation with CDMA:

![Diagram showing power distribution for different scenarios.](image)
Uplink

Stand alone:

- Technology
  - Visible
  - Infrared
  - RF
  - Millimeter wave

- Except RF, not currently ubiquitously deployed

Converged:

- Heterogeneous networking:
  - Use another currently available technology:
    - Wi-Fi
    - Cellular

- Easier for market entry as all wireless devices already equipped.

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Backhaul and Data Distribution

To extract the full benefit of VLC, need many luminaries, but what infrastructure is needed to support this?

- Gbps per user to tens of users
- DSL or cable modems not sufficient
- Ethernet to the room not sufficient (PoE ?)
- Couple VLC with widespread PON deployment
Convergence with Existing Systems

- Benefits of technology have to compensate for increased cost.
- Make people feel good about previous investments
- Convergence with 5G?
- Accelerate fiber to the home?
Lighting Features

- Uniform illumination ...
  - Not like RF, since each cell served by many base-stations
- Dimming: game changer ...
  - the goal is no longer to minimize $E_b/N_0$
- Rendering: all is for naught if humans don’t like it.
- Cost remains an issue
Applications
Outside the Box Applications …

- Wireless docking
- Data centers/cloud computing centers
- Underwater communications
- Health monitoring systems
  - Implanted devices
  - Activity monitoring
- Specialized uses:
  - Nuclear reactor monitoring
  - Manufacturing robot control and telemetry

...
Open Questions

- What are the fundamental limits of VLC networks?
- What is the killer app?
- How does it converge into the current telecomm market?
- Can communications drive lighting?
- How can emerging technologies exploit VLC:
  - Internet of things (peer-to-peer ?)
  - Cloud computing
  - Personalized health care
  - 5G
  - ...

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A bumpy road ahead

Years of heavy research and only highly specialized or kitschy products

Low data rate implementations for indoor positioning

Sudden large-scale commercial buy-in as:
  o Usurp Wi-Fi’s position as the standard for indoor lighting, with Wi-Fi as back-up
  o Communications from every device/system via illumination

→ total convergence
“We can easily forgive a child who is afraid of the dark; the real tragedy of life is when men are afraid of the light.”
--- Plato

“Women will then build the VLC systems.”
-- Maite Brandt-Pearce, September 2014

Questions?