

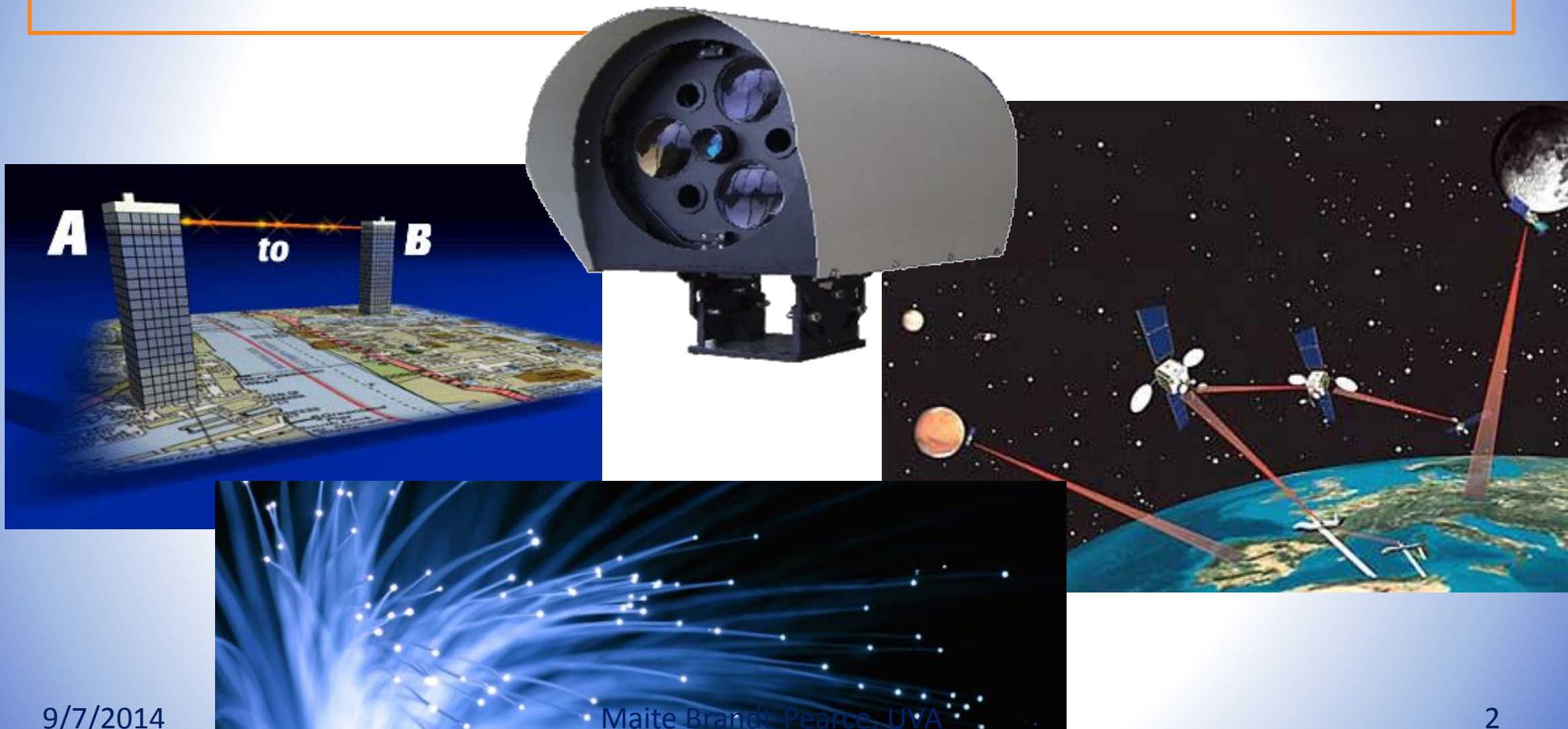
The Future of VLC: Potential and Limitations

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9/7/2014

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?

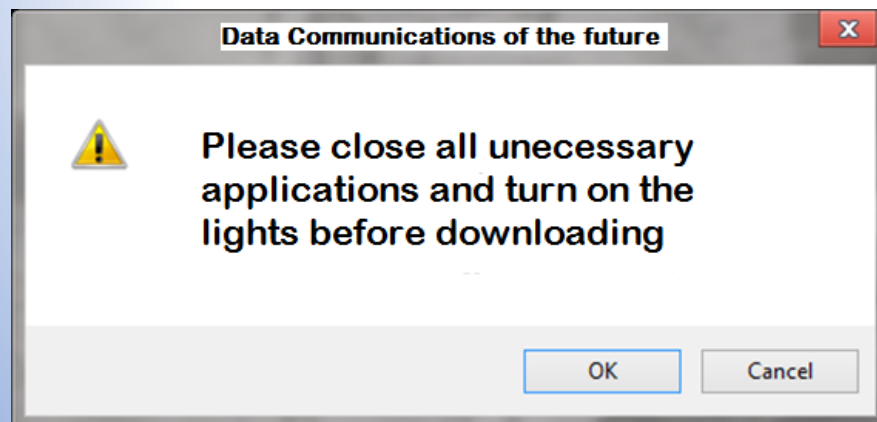
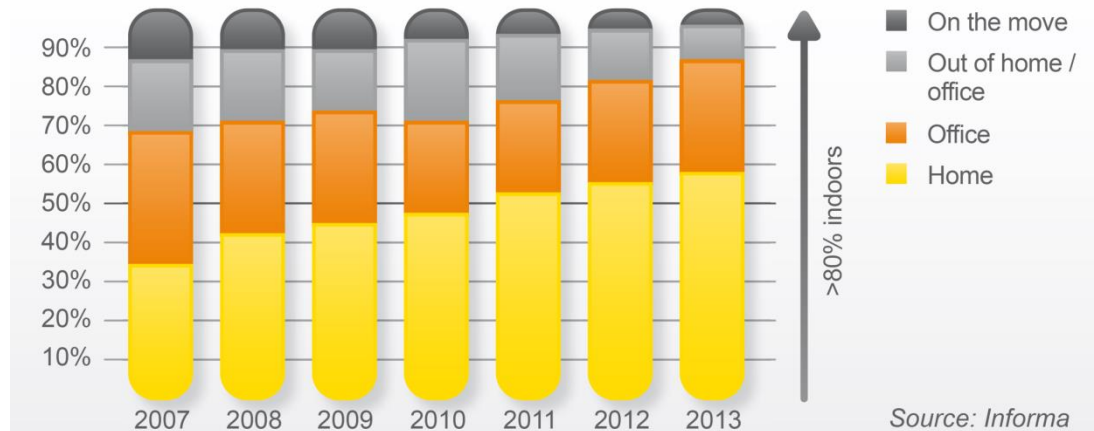
Recipe for Adoption of New Technology

- ❖ 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 ...

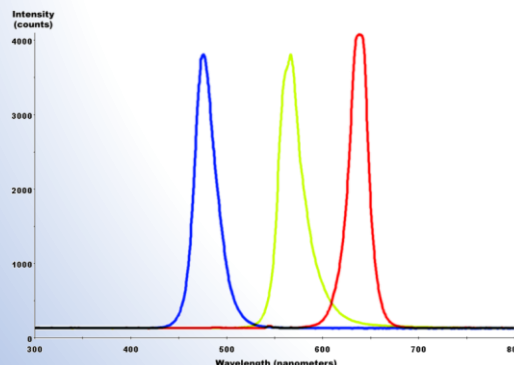
- ❖ Ubiquitous
- ❖ Noncoherent and easy to modulate
- ❖ Bandwidth limited to few MHz
- ❖ Tri-band offers λ multiplexing



Luminaries ...

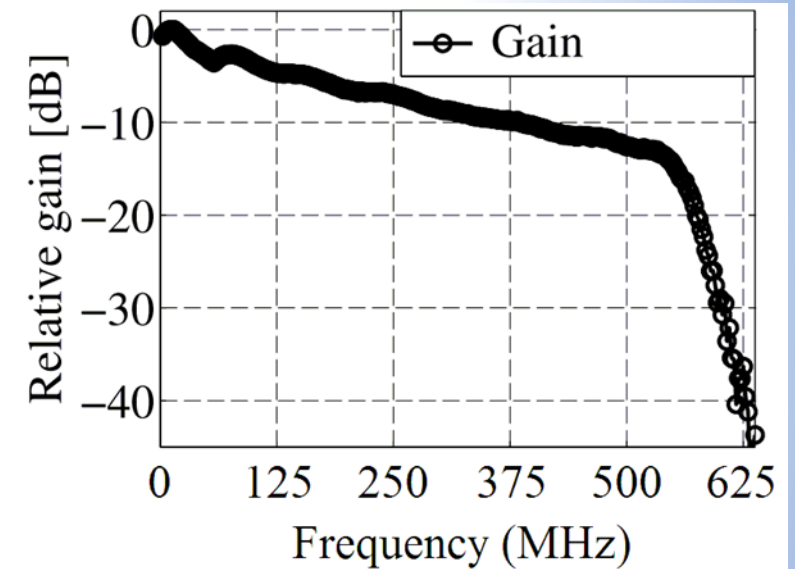
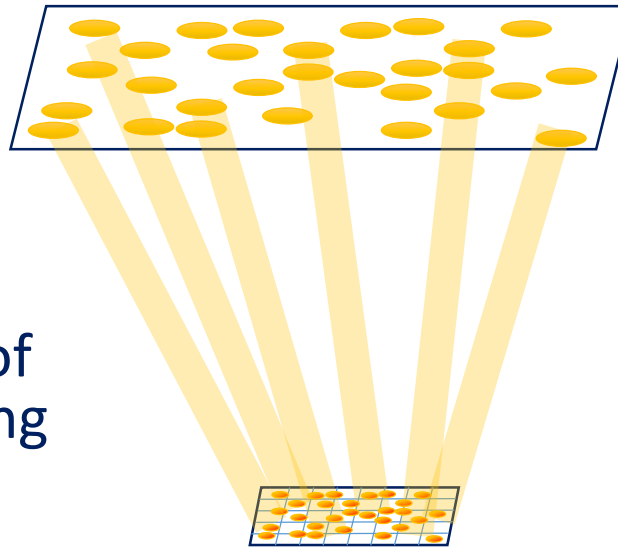


- ❖ So much potential, but how do we access it easily and cheaply?



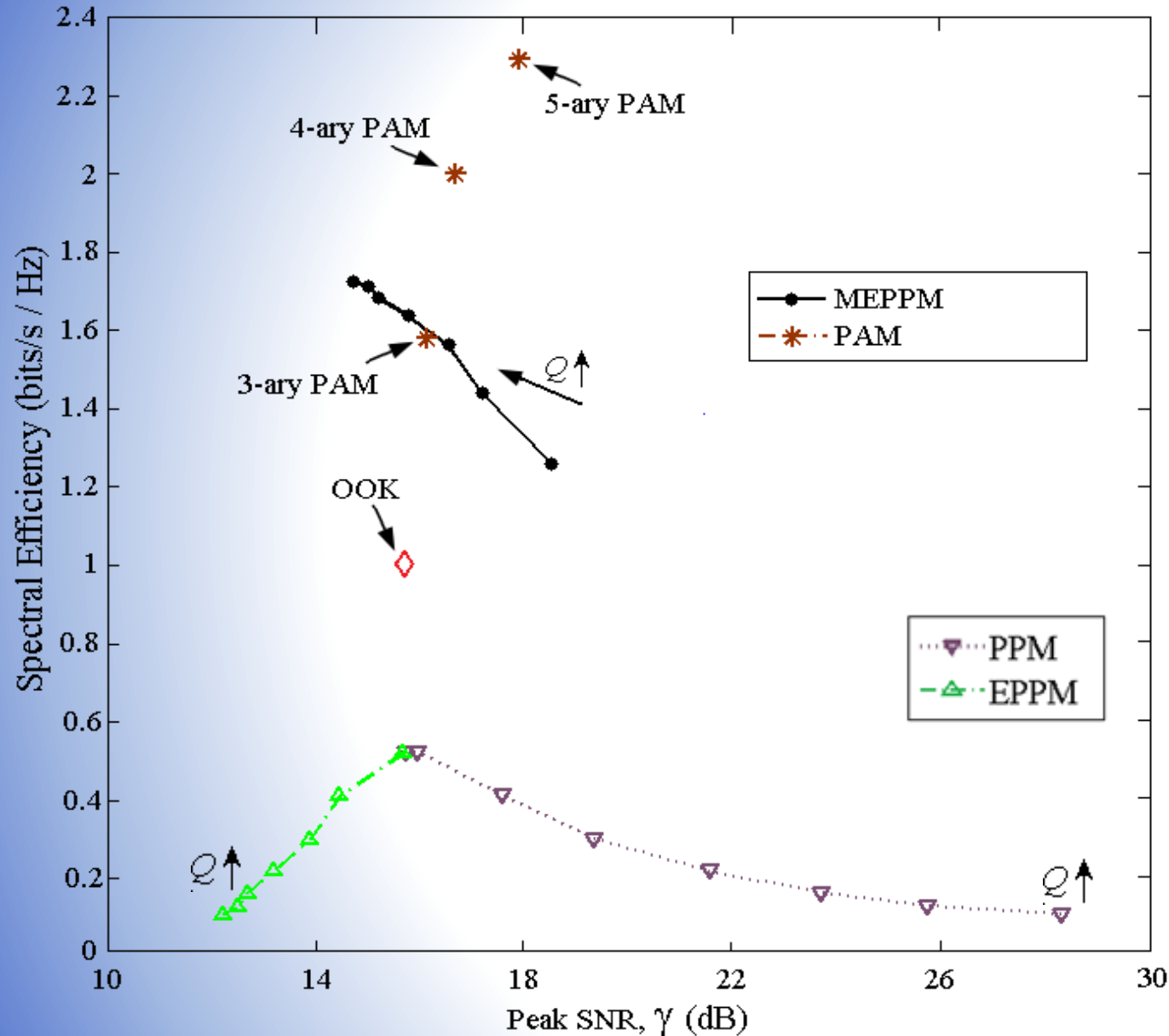
Improving Information Rates

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



Tsonev-2014

Modulation



❖ Issues:

- Flicker
- Dimming
- LED rise-time
- LED nonlinearity

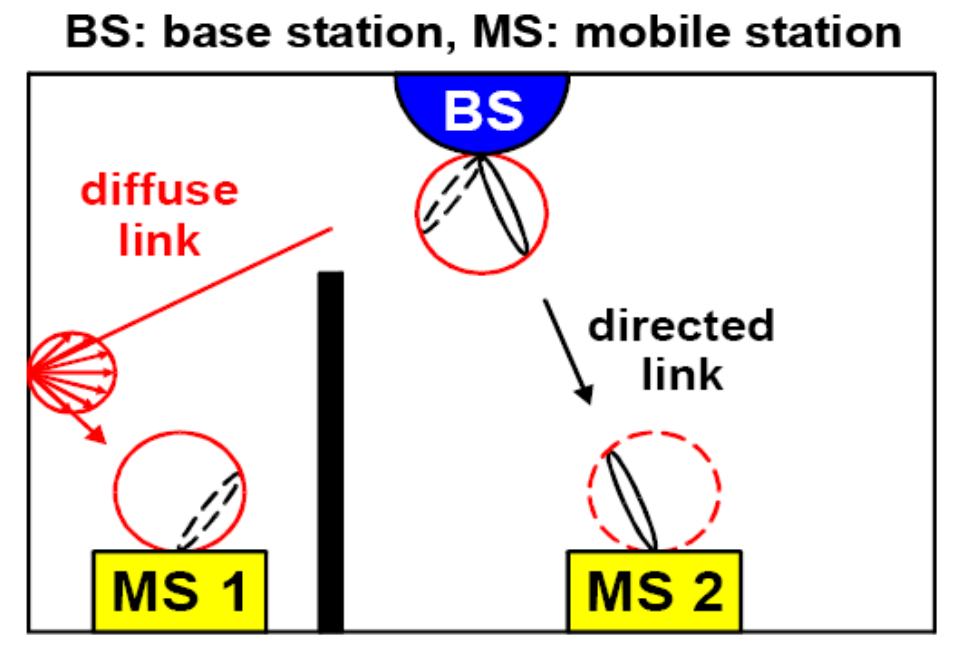
❖ Options:

- 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



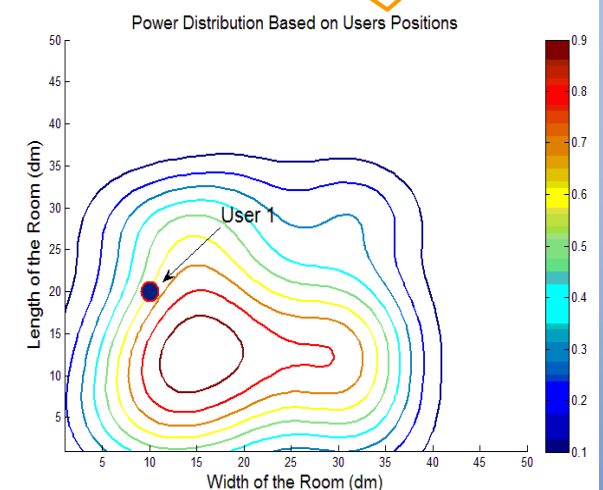
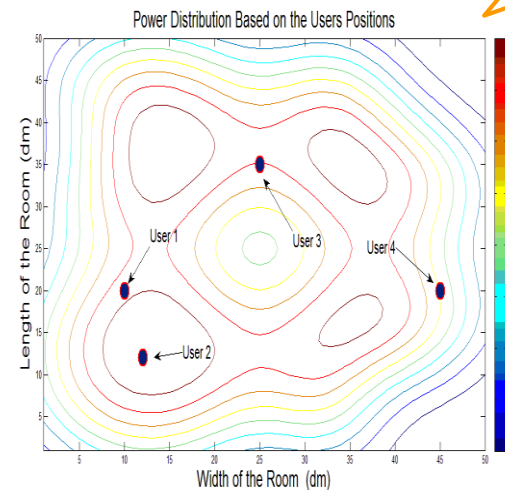
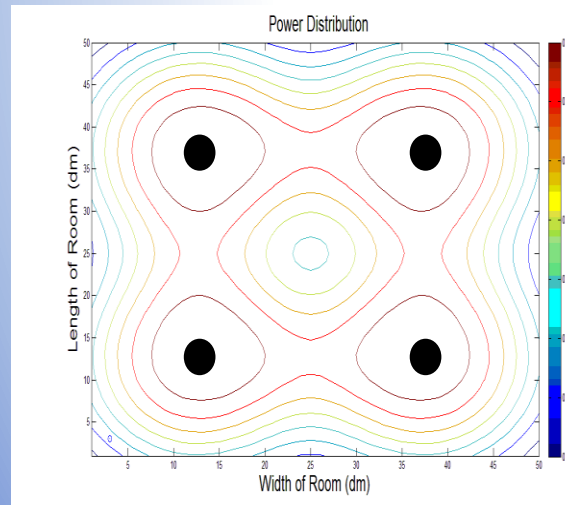
Jungnickel, 2014

Multuser 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:

4 users

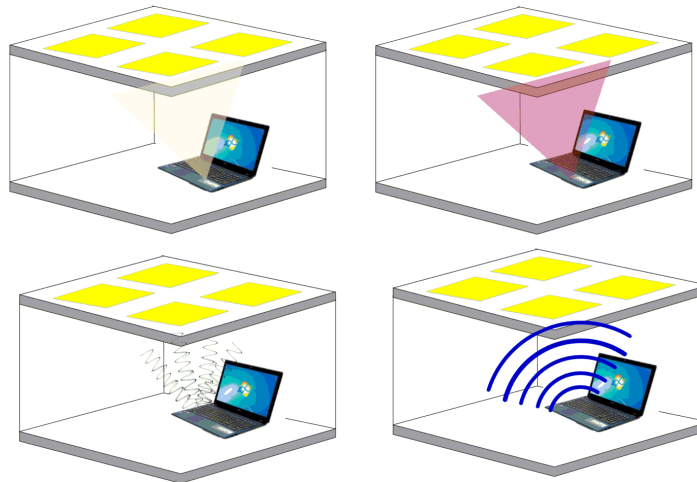
1 user



Uplink

Stand alone:

- ❖ Technology
 - Visible
 - Infrared
 - RF
 - Millimeter wave
- ❖ Except RF, not currently ubiquitously deployed

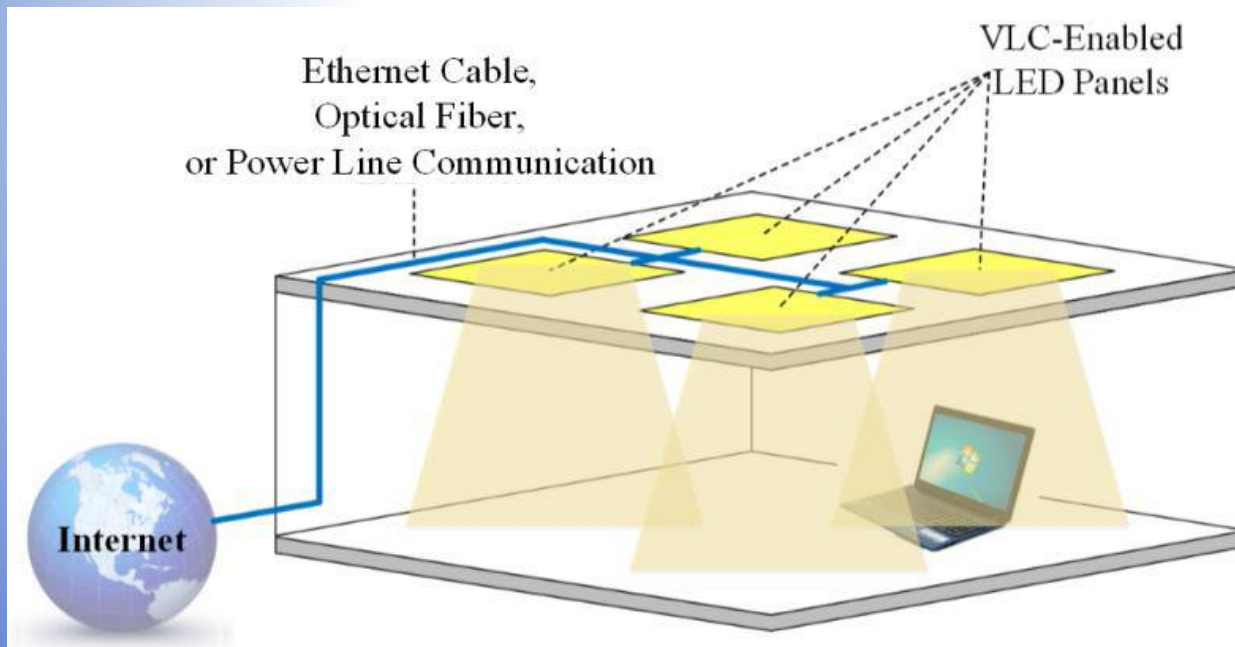


Converged:

- ❖ Heterogeneous networking:
Use another currently available technology:
 - Wi-Fi
 - Cellular
- ❖ Easier for market entry as all wireless devices already equipped.

Backhaul and Data Distribution

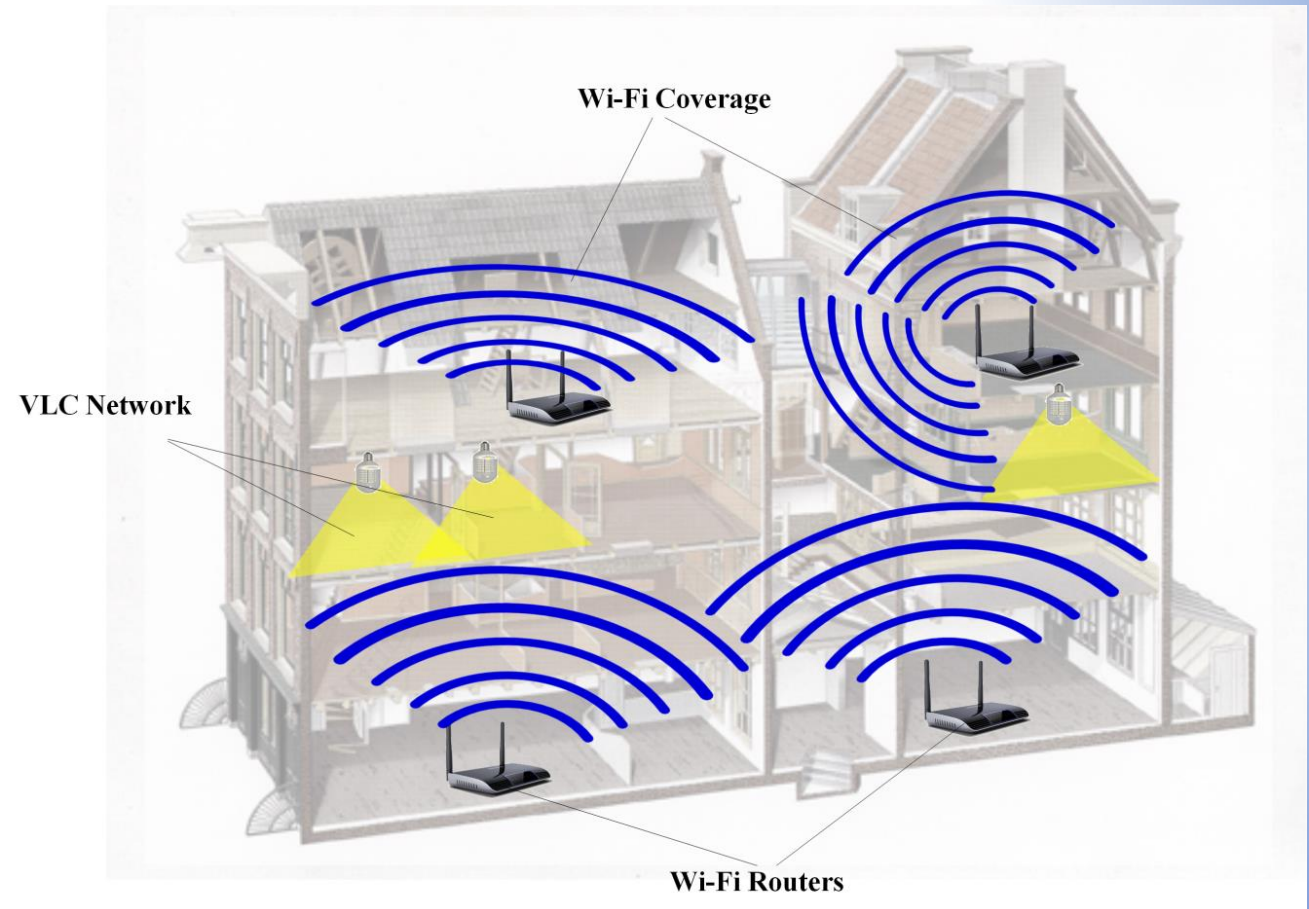
To extract the full benefit of VLC, need many luminaries, but what infrastructure is needed to support this?



- ❖ 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 ...

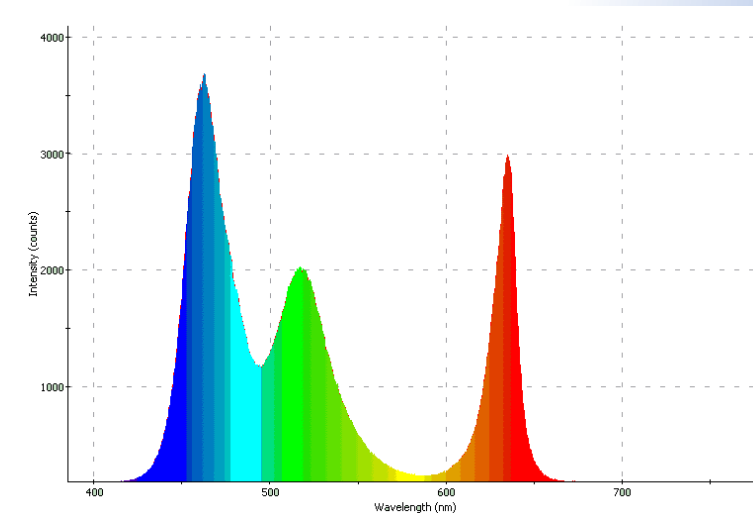
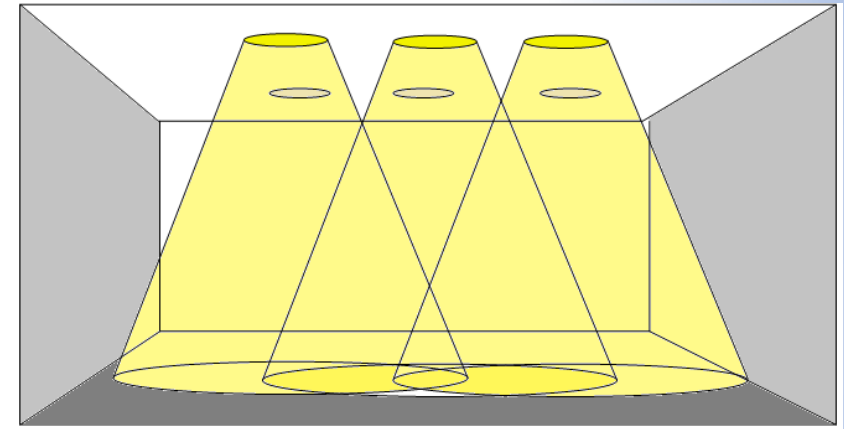
→ Not like RF, since each cell served by many base-stations

❖ Dimming: game changer ...

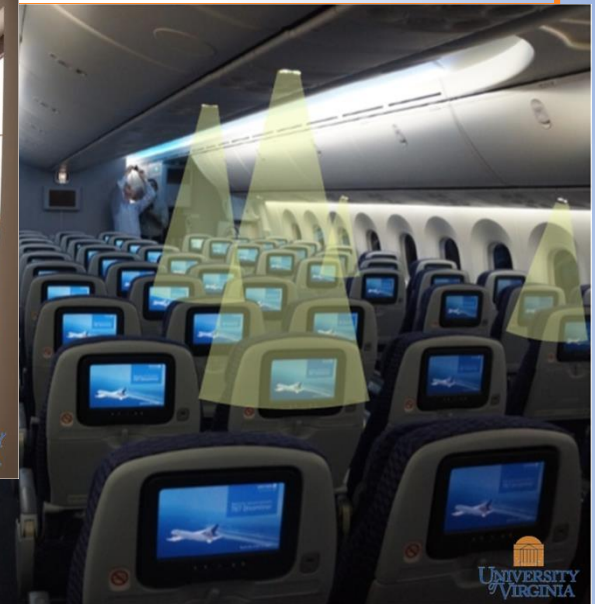
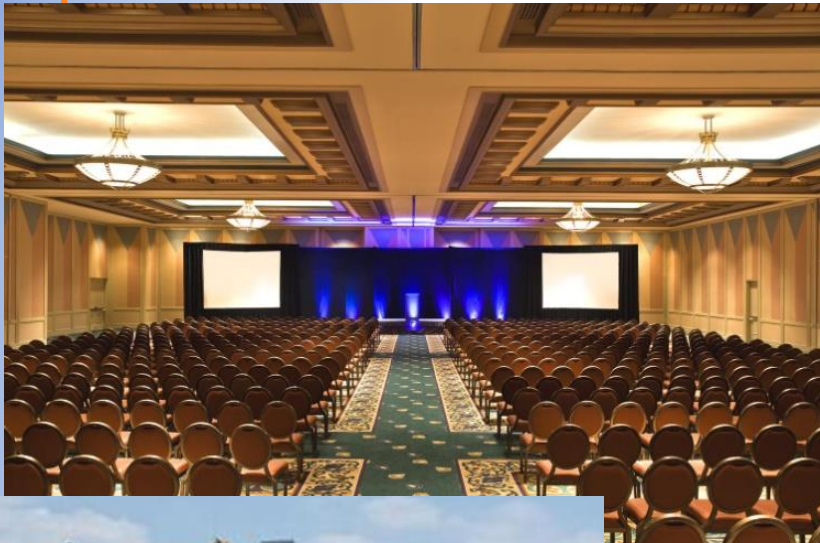
→ the goal is no longer to minimize E_b/N_0

❖ Rendering: all is for naught if humans don't like it.

❖ Cost remains an issue



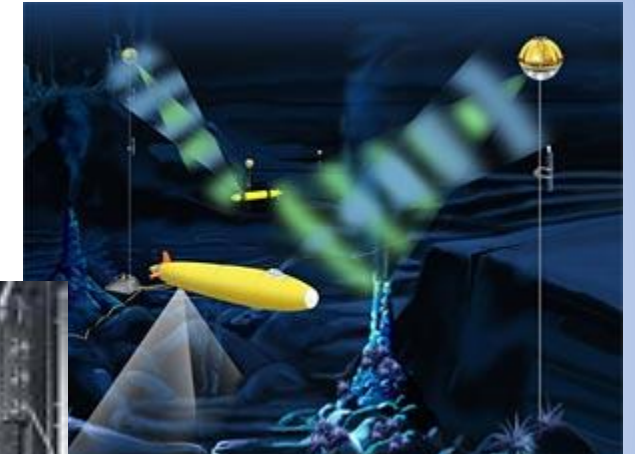
Applications




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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
 - ...

My Vision ...

- ❖ 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:
 - Usurp Wi-Fi's position as the standard for indoor lighting, with Wi-Fi as back-up
 - 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?